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CAST ALUMINUM COMPONENTS PHASE I VOLUME 1

U.S. ARMY TACOM

February 1983

by R. B. Hare/R. L. Malik

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TACOM Technical Representative G. K. MacAllister
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Stress Corrosion	Welding	Cost Analysis

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The object of this program was to produce a one-piece cast aluminum alloy turret to replace a welded lightweight turret and reduce the cost of manufacturing. During the first phase of a planned three phase program, the following steps were achieved:

1. Aluminum alloy A206 was selected as the most economical and commercially available high strength alloy with potential ballistic properties

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20. ABSTRACT (Continued)

suitable for the cast turret.

2. Cast turret design was established with modifications to achieve acceptable ballistic properties.

3. Casting techniques were established by the production of cast rear quarter and rear half turret sections. Directional solidification, controlled by chills and insulated risers, was one technique used for these large castings.

4. Satisfactory soundness of castings was verified by radiographic inspection.

5. Alloy A206-T4 was determined economically more desirable than A206-T71 by evaluation of mechanical, metallurgical, stress corrosion and ballistic properties and heat treatment operations.

6. Design evaluation indicated that the one-piece cast turret with A206-T4 alloy and equivalent ballistic properties may result in a 10% increase in weight.

7. Economic evaluation from Phase I showed that one-piece turret was the most economical. Estimated savings of $2,000 per unit would be achieved by the reduction of labor intensive welding and machining operations.

PREFACE

This report examines aluminum armor casting alloys, their manufacturing methods, and the technology for producing low cost castings to replace the labor intensive plate-welded turret of M2/M3 Bradley Fighting Vehicles (BFV). The turret was selected because of its cost saving potential and relatively complex shape. Results presented in this report show that a cast turret can meet cost and weight objectives with ballistic integrity equivalent to the welded turret.

A206 aluminum alloy was selected for castings because of its high ballistic strength and low cost.

ECK Industries was the subcontractor selected for Phase I program because of its foundry expertise and facilities available to cast, heat treat, and X-ray large A206 castings.

This report was prepared by Ram L. Malik, Associate Staff Engineer under the supervision of Ron Hare, Manager MM&T.

Notable contributions were made by Gerard Ezcura and Angelo Rubero in the mechanical and ballistic test programs.

Richard Faucett, who has been most helpful in supplying literature and offering sound suggestions, materially enhanced the quality of this report.

The helpful criticisms, editing, and study of arrangements by R. L. Shirley has been of great advantage.

The Technical Representative for the program for USA TACOM was Mr. George K. MacAllister, DRSTA-RCKM.

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EXECUTIVE SUMMARY

This report covers Phase I effort of examining armor casting alloys, their manufacturing methods, and the developing technology for producing low cost castings to replace the labor intensive plate welded turret of M2/M3 Bradley Fighting Vehicles (BFV).

The turret was selected because of its high cost saving potential and relatively complex shape. Results presented in this report show that high quality aluminum castings with complex shape and varying wall thickness can be made which will meet cost and weight objectives with ballistic integrity equivalent to the welded turret.

A206 aluminum alloy with T4 heat treatment was selected for castings because of its high ballistic strength and low cost. Metallurgical and ballistic tests on cast samples confirmed a weight increase of 8% for casting to match its ballistic performance to a plate welded turret.

Weldability characteristics of A206 to other aluminum alloys remain inconclusive and additional tests are planned in Phase II to define weld joint integrity.

The cast turret will provide substantial cost savings per turret and will require less machining time than a plate welded turret.

CAST ALUMINUM COMPONENTS - PHASE I

1.0 INTRODUCTION

The objective of the Cast Aluminum Components Manufacturing Methods and Technology (MM&T) program is to reduce the cost of the Bradley Fighting Vehicles (M2 and M3) by replacing the labor intensive welded plate turret with a single piece casting. The M2 welded turret is shown in Figure 1 and its potential replacement casting is shown in Figure 2. Figure 3 illustrates the cast turret showing a proposed armor design modification.

The turret was chosen for development because of its cost saving potential. In addition, the choice of the turret forces consideration of some important materials and manufacturing methods questions:

- ° Can high quality aluminum castings be made of thick sections with a relatively complex shape?
- ° Can armor protection be maintained without excessively increasing weight?
- ° Can sufficient casting integrity be attained with existing aluminum alloys?
- ° What special techniques are required for weld repairs and attachment of bracketry?
- ° What special problems might be encountered during machining of the turret casting?
- ° What specifications will guarantee material properties for quality acceptance purposes?

To answer these questions, a three-phase program began in October of 1980. This report documents the findings of Phase I.

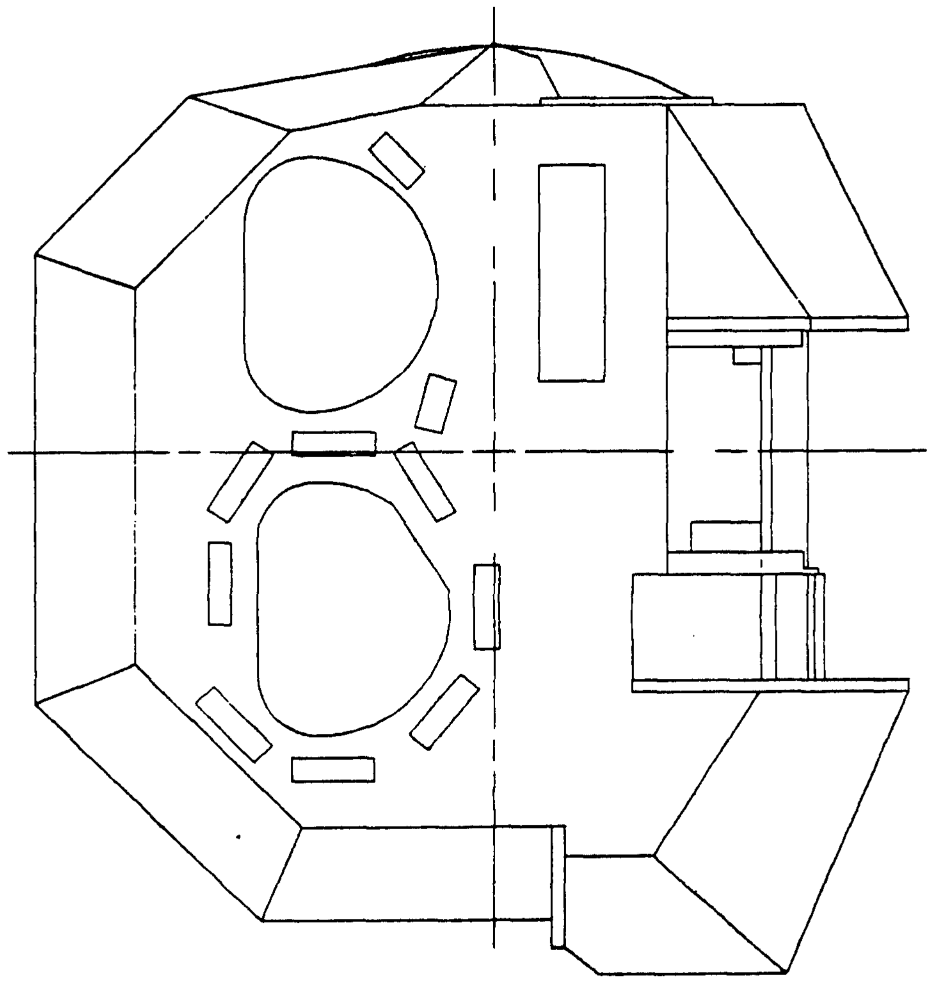


Figure 1 Welded Lightweight Turret

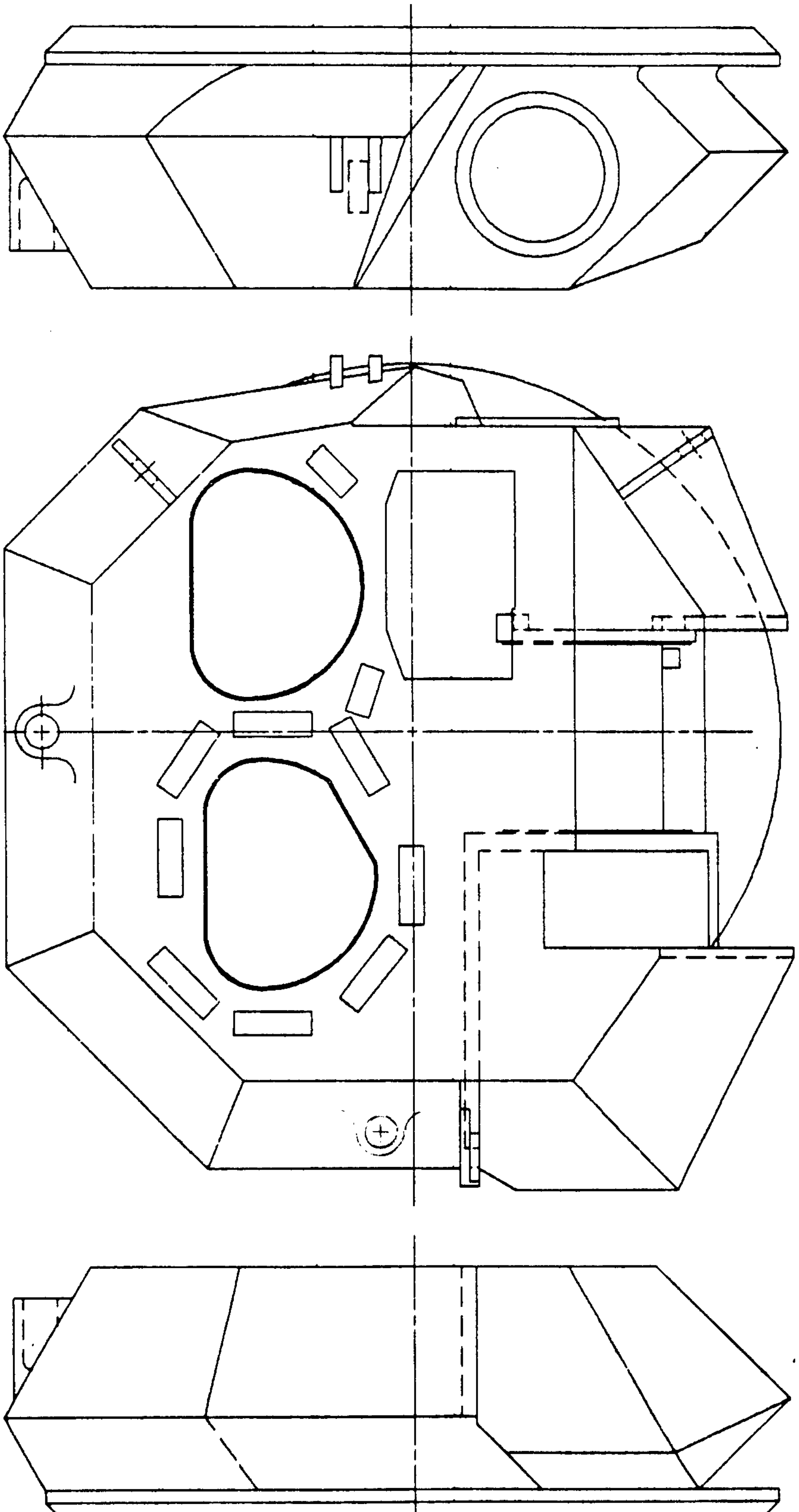


Figure 2 Potential Replacement Casting

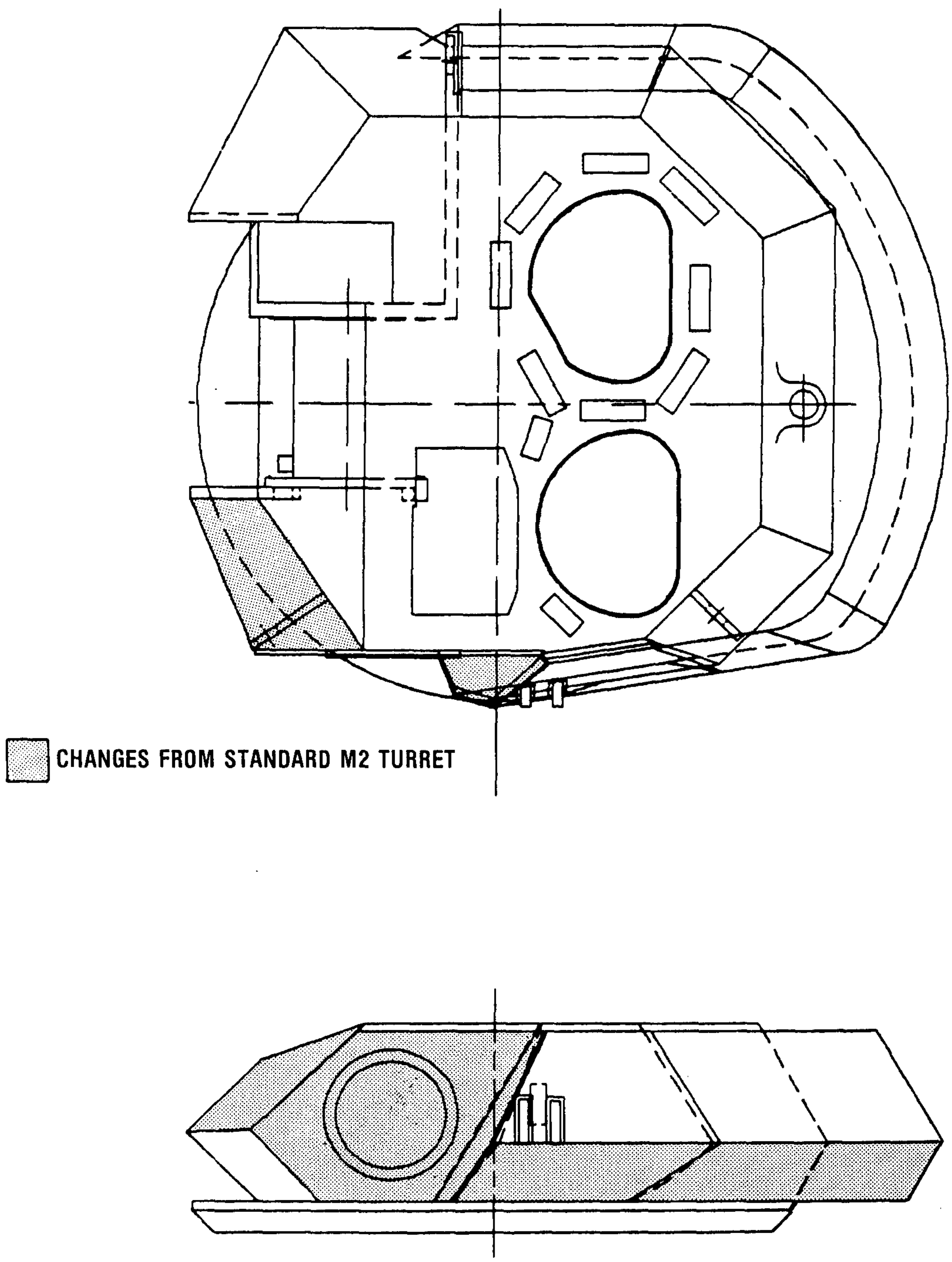


Figure 3 Cast Turret Showing Proposed Modified Armor Design

The recently completed first phase included selection of the aluminum alloy (A206), heat-treatment specifications (T-4), pattern and mold construction, and pouring of a series of sample castings to establish foundry procedures. Phase I also included radiographic, metallurgical, mechanical, corrosion, and ballistic tests on sections of an actual turret casting.

The second phase will include casting of front sections for validation of ballistic acceptability and at least two castings. One full-size casting will be machined to determine tooling and bracket installation requirements and the other will be used for Government ballistic design validation. Phase II will conclude with complete cost, weight, and ballistic analyses.

The third phase will verify all performance criteria, including durability and weapons accuracy. Final changes to design details will be made and all documentation will be submitted for production of cast turrets.

A summary of significant conclusions and results from Phase I follows. Detailed results are documented in the body of this report. The appendices contain data which may be used for confirmation of the conclusions or for future applications.

2.0 CONCLUSIONS

2.1 Alloy Selection

The aluminum casting alloy selection was based on recent favorable experience with A206 alloy for a lightweight final drive housing. Industry experts agreed that A206 aluminum alloy is the only commercially available alloy that might satisfy cost and weight objectives. The only alternative considered was A201. However, the cost due to high silver content of the alloy removed it from consideration. Further, at least ten foundries responded to a purchase request for casting the complete lightweight turret in A206 alloy.

The ballistic and metallurgical tests on sample cast plates and cast turret sections have confirmed that the T4 condition of heat-treatment provides adequate properties at the lowest cost.

2.2 Metallurgical Integrity and Foundry Practice

Aluminum alloy A206 requires special handling, but experienced foundries have had no difficulty in casting quarter and half-sections of the turret with varying thicknesses. Metallurgical and radiographic tests performed on cast test plates and cast turret sections show few flaws in the material. The impact of typical flaws on ballistic performance appears to be minor and will be explored further in Phase II.

Large A206 castings require the use of techniques such as directional solidification, which can be controlled by chills and insulated risers.

2.3 Armor Design

A cast design offers the opportunity to vary thicknesses proportional to obliquity, which is not possible in the welded plate version. Results from ballistic testing of cast plates were used in designing turret wall thicknesses. Results from testing of the quarter section castings were used to refine patterns for the half-section casting.

The overall armor design of the welded plate and cast versions include armor steel applique and spaced steel armor. An important goal of this program is to provide protection equivalent to the welded version, without a weight increase. Because the ballistic properties of the cast material are somewhat inferior to those of wrought material, the overall armor design is critical to achieving this goal. Phase II will address armor design in detail.

2.4 Welding

Preliminary tests have been performed to evaluate the weldability characteristics of A206 and related effects of welding on castings. To determine an acceptability level of weld joints joining castings, and castings to wrought alloys, limited mechanical tests were performed. More tests will be conducted with different filler alloys to determine how welding heat and weld metal dilution will affect joint performance.

The results of the tests performed so far do not clearly indicate predictable mechanical properties of joints welded with 2319 filler alloy. However, A206-T4 welded with 2319 filler alloy and postweld aged, performed slightly better in tensile and yield strength categories than did A206-T4 in the "as welded" condition. A206-T4 in the "as welded" condition showed the highest elongation. Although these results are not conclusive, they do indicate that A206-T4 could be welded to other aluminum alloys with special techniques to make a reasonably strong joint. Additional weld tests are planned in Phase II of this program to clear up these uncertainties of soundness of weld joints. Test data on welding is enclosed in Appendix C.

2.5 Preliminary Cost Predictions

Because a full turret has yet to be cast, we cannot accurately forecast the production cost of the final one-piece cast turret. But comparable cost indicators point toward a lesser cost for the cast turret in comparison to the welded plate turret. The casting will need no welding other than weld repairs and welding few brackets; this will save machining time which otherwise is required for plate

edge preparation. Elimination of welding fixtures will free up costly shop space and handling facilities. One-piece casting will eliminate shop control required for the handling, identifying, and storing of many individual plates. This will improve efficiency of operations and result in better material control.

A thorough cost analysis will be made in Phase II after a full turret casting has been machined and more experience is gained with production of welded turrets. It is estimated that the unit savings with the cast turret will be substantial. It is estimated that unit savings will be at least $2,000. These savings may prove higher as detailed costs of the welded version are identified.

2.6 Preliminary Weight Predictions

The results of this Phase I effort indicate that it is feasible and economical to manufacture a one-piece casting of the turret that meets the performance levels of the welded turret.

The unmachined prototype rear half and rear quarter cast sections weigh about 10% more than the calculated weight of the corresponding welded rear sections.

However, planned weight reductions for the full castings, such as redesign of the bottom plate and removal of material not present in the welded plate design, should reduce the casting weight to less than 8% higher than the welded plate version.

3.0 TECHNICAL DISCUSSION

3.1 Approach Outline

The following approach has been used to develop casting drawings and casting techniques to produce a ballistically equivalent turret. Currently, the M2 turret is a piece-welded structure fabricated from 7039 and 5083 aluminum alloy armor plate and overlaid by steel applique or spaced laminate armor. Figure 4 is an overall view of the 1/8 size model of the turret casting.

- Select an appropriate aluminum alloy having good ballistic properties at a cost competitive with the plate materials.

- Use the welded turret as the basic shape and modify to best fit casting practices. Based on known ballistic and material properties of the casting material selected and the material used in the welded turret, select appropriate wall thicknesses of the casting with or without steel armor plates, for an economical and ballistically sound casting with minimum weight.

- Perform ballistic and metallurgical tests on plates cast out of the selected alloy, with varying heat treatments and on both chilled and unchilled areas.

- Modify drawings to reflect test results.

- Establish foundry techniques for minimum cost and ease of production.

- Cast sections of the turret and perform radiographic, ballistic, and metallurgical tests on these castings.

- Modify the drawing to reflect test results.

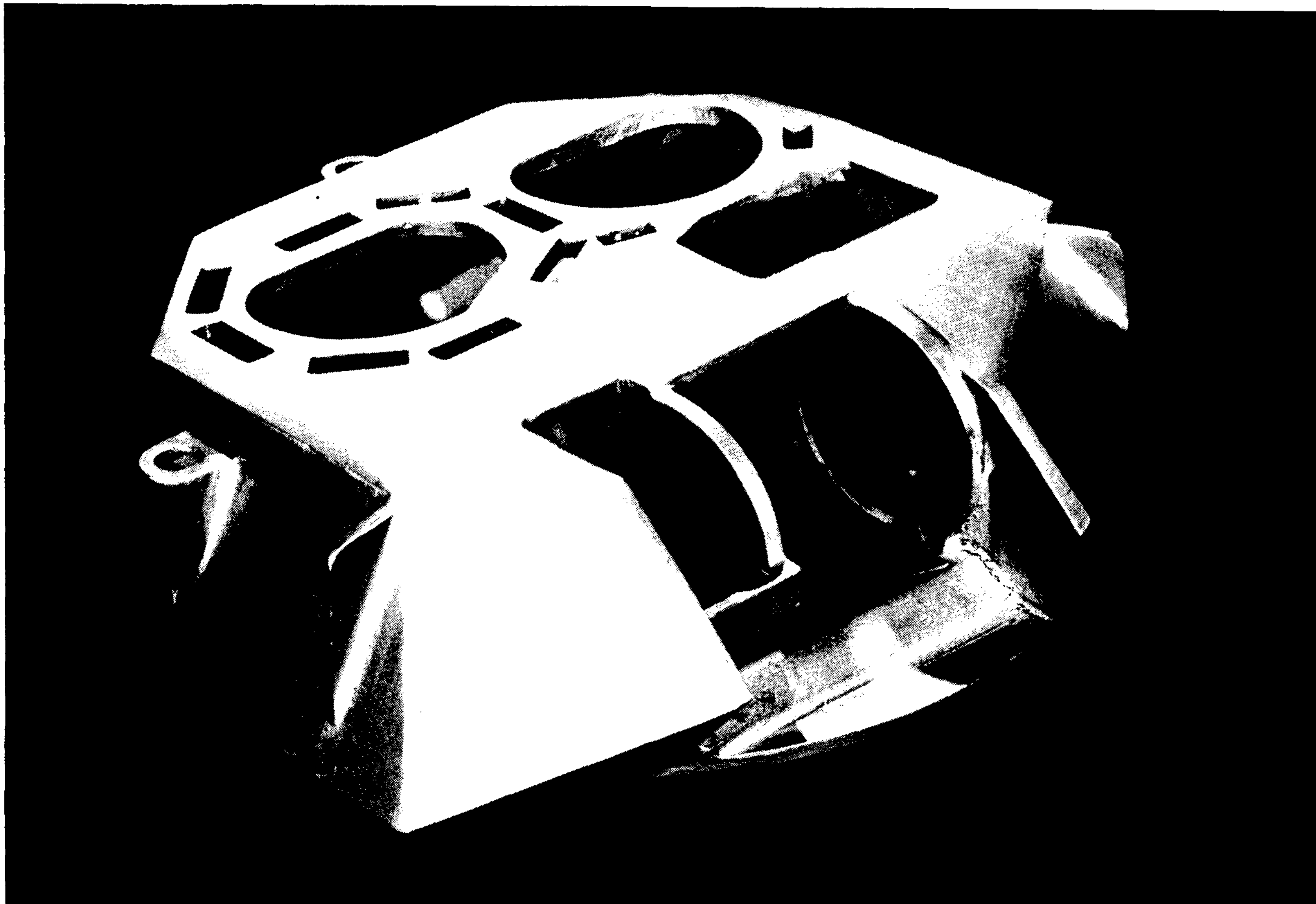


Figure 4 Overall View of the 1/8 Size Model of the Turret Casting

- Cast and test a complete rear half turret.
- Modify the drawing to reflect test results.
- Complete pattern for the full casting.
- Perform welding tests to develop weld procedures.
- Perform preliminary cost and weight analyses.

3.1.1 Design Considerations

The primary design consideration was to produce a turret casting that would closely resemble the welded version and would have equivalent ballistic protection. The turret would be designed to minimize the number of cores required for cost effectiveness. The following specific considerations in the cast turret were used in the design:

- Provide armor protection equivalent to the present welded turret.
- Maintain the basic shape of the turret and retain the same mounting provisions for attached items.
- Redesign other mounting provisions, if necessary, without altering the locations of mounted subassemblies.
- Cast in some of the mounting brackets and pads. These brackets or pads would eliminate welding and would need little or no machining. Some of the items considered for integration with the casting were antenna mount, lifting eyes, armor mounting provisions, sight resolver mount, service light brackets, 7.62mm door hatch brackets, turret control box bracket, position indicator bracket, TOW drive mounting lugs, gyro mount bracket, and gun elevation drive mount. All represent additional cost savings.

- Minimize the weight of the casting.

- Make the ejection chamber smaller by eliminating the jog in the top plate and bring in the plenum side plate.

- Make no change to the outside profile of TOW trunnion, left closure, and lower left plates. The upper plate is to remain unaltered.

- Eliminate machining from periscope holes and other areas where cast surfaces, with reasonably close tolerances, can be used without machining.

3.1.2 Alloy and Heat Treat Selection

The selection of aluminum alloy was based on recent favorable experience with the A206 alloy for a final drive housing and FMC's confidence in A206 ballistic performance. Figure 5 shows the relative ballistic performance of A206 against other aluminum alloys. FMC's ballistic test results reconfirm the accuracy of weight merit-rating for A206-T4 alloy in comparison to 5083 and 7039 alloys as shown in Figure 5.

Alloys A201 and A202 are the only other commercially available alloys that match or exceed A206 ballistic properties. Both of these alloys contain silver (0.4 to 1.0%) and are high in cost.

TRIALCO, INC. performed tests on several high-strength and high-toughness alloys to characterize A206 alloy with respect to others. In the high strength categories, A206-T7 was shown to have properties somewhat lower than A201-T7, but was much stronger than other alloys tested. In the high toughness category, A206-T4 was shown to equal or exceed A201 properties. Figure 6 compares high-strength and high-toughness alloys.

Thus, A206 has ductility and strength approximately equivalent to A201 alloy, but at fraction of the cost. A206 is a high copper alloy that

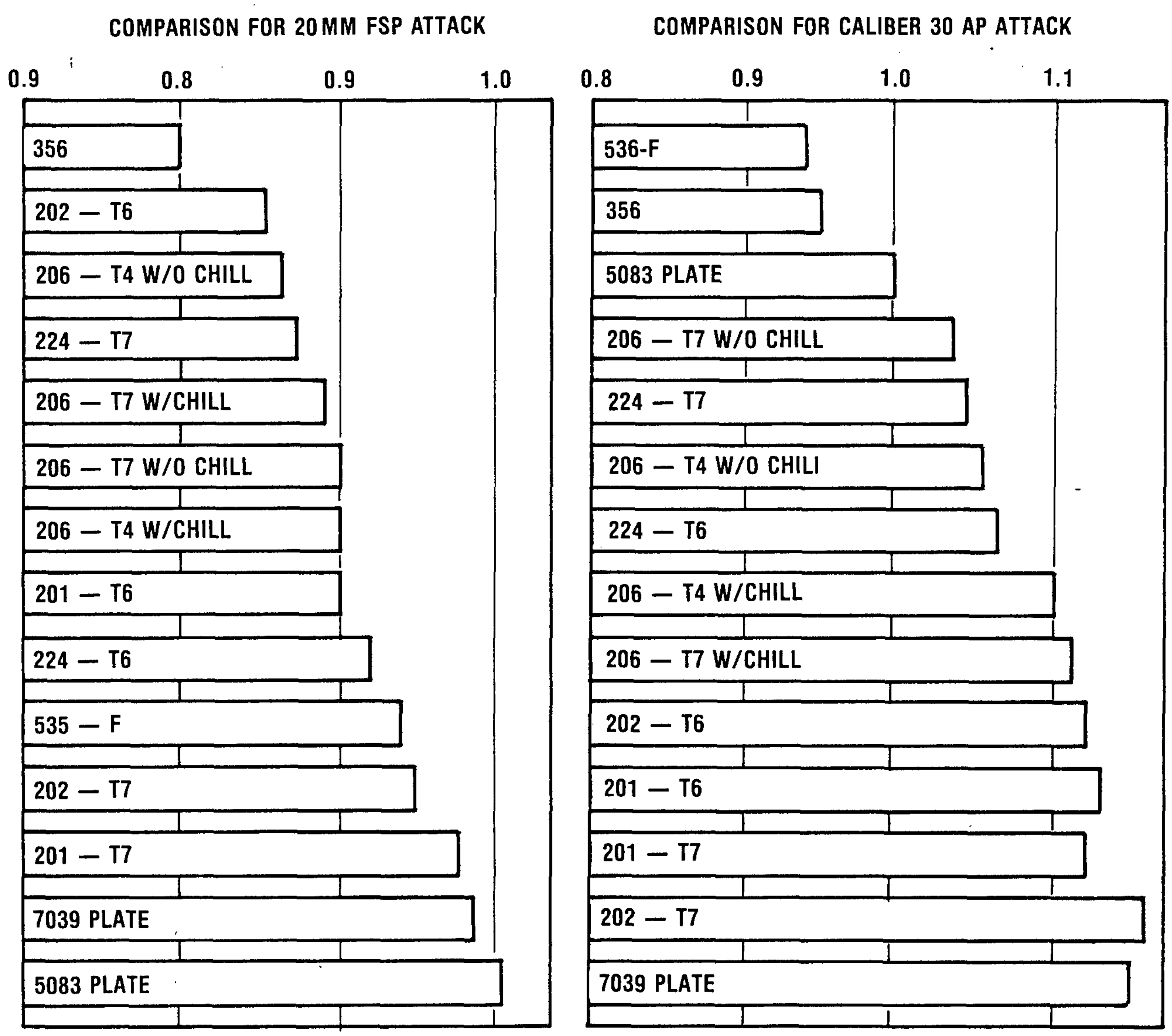


Figure 5. Ballistic Weight Merit-rating for High Strength Cast Aluminum Alloys. (Ratings are made using 5083 Aluminum Armor Plate (MIL-A-46027) as 1.0.)[1]

(1) A. L. Kearney and J. Raffin, "Mechanical Properties of Aluminum Castings Alloys X206.0-T4 and XA 206.0-T7," paper presented at American Foundrymen's Society's 81st Casting Congress, Cincinnati, Ohio, April 26, 1977.

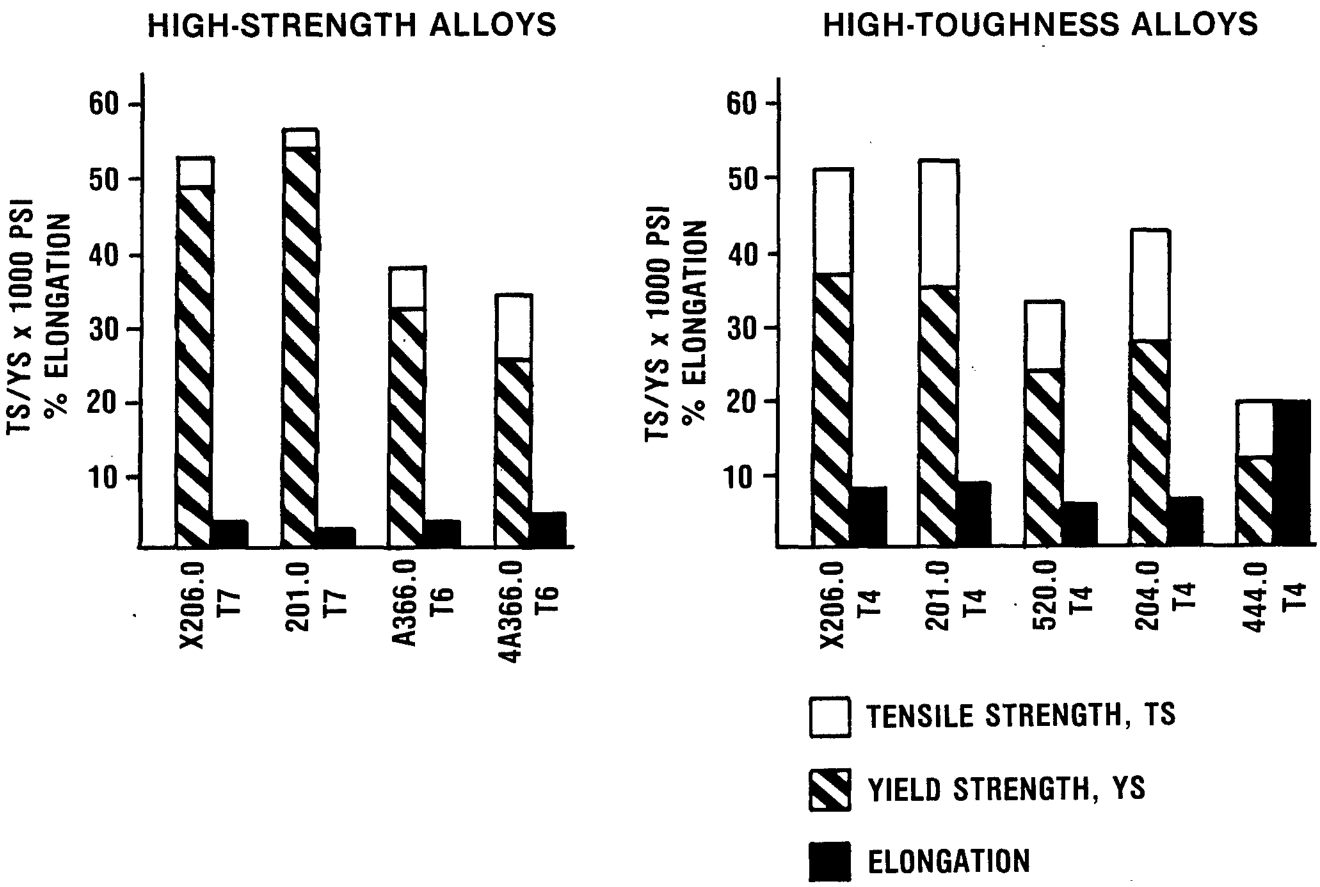


Figure 6 Tensile Properties of "High Toughness" and "High Strength" Aluminum Casting Alloy Groups.(2) (Note high ductility alloy is also high toughness alloy. For sand mold, solidification time is 50 seconds.)

(2) Ibid.

can be heat treated to attain a variety of mechanical properties. The T4 condition is attained by solution heat-treating, quenching, and naturally aging at room temperature to a substantially stable condition. Ballistic and metallurgical tests on sample cast plates and cast turret sections have confirmed that the T4 condition of heat treatment is suitable and economical for A206 alloy.

The T6 condition is attained by solution heat treating, quenching, and artificially aging to the most desirable combination of strength and ductility. However, the T6 temper is more susceptible to stress corrosion than the T4 or T7 temper. Overaging (condition T7) applies to products that are solution heat treated and artificially aged beyond the condition of maximum strength to provide dimensional stability, lower residual stresses, and improved resistance to corrosion. T7 heat treatment condition also qualifies and meets Federal Test Requrements for Stress Corrosion Cracking. But most recent ballistic tests of castings heat treated to the T7 condition indicate that T7 is no better than T4, and T4 heat treatment costs considerably less than T7. Final selection of the heat treatment condition (T4 or T7) will be made after a prototype turret casting is machined and allowed to age for dimensional stability. An excessive dimensional shift in machining areas will make T7 more desirable.

3.1.3 Casting Process Selection

Choice of casting process depends largely upon economic considerations and on metallurgical advantages and limitations. Out of the two possible casting processes, namely, sand casting and mold casting, sand casting is the only economically available process for castings of this size. Molds of self-set sand need no preheating or baking of cores and can give a reasonably good surface finish.

The factor which contributes most to the soundness of the casting is the location of gates, risers, runners, sprues, and chills. Aluminum, upon freezing, contracts 5% to 7% in volume. To produce a sound cast structure, liquid metal in risers should feed back into the

intergranular spaces formed upon freezing. This desired freezing and feeding sequence is achieved by directional solidification, in which freezing starts first in the remote areas of the mold cavity, and the zone of freezing and feeding progresses towards the risers. Directional solidification is a function of temperature gradient which, in turn, is controlled by the location of chills, risers, sprues, and gates.

The following series of photographs (Figures 7 through 19) show the castings and patterns in various stages of manufacture.

3.1.4 Ballistic Tests

Ballistic tests were performed on cast plates and cast turret sections to establish the feasibility of producing a ballistically sound cast turret. Testing of cast plates of various alloy compositions with varying heat treatments, made it possible to select the most suitable combination of alloy and heat treatment. Using results from previously performed ballistic tests by the contractor, aluminum alloys 356, 520, 204, 224, 535 were removed from consideration. Alloy A201 was eliminated, due to its high cost. A206 plates in T4 and T7 conditions were tested and limited tests were performed on 356-T6 alloy for verification of results on record. Results established A206-T4 as the combination of alloy and heat treat offering maximum protection against KE threats.

Tests were performed on cast test plates to establish V_{50} ballistic limits using both .30 caliber armor piercing (AP) and 20mm fragment simulation projectile (FSP). Results indicated a thickness increase of 16% to replace 5083 armor alloy plate so as to provide equivalent protection under FSP attack. An increase of 13% in wall thickness is required to replace 7039 plate for the same protection under AP attack. The 1.5-in. thick 5083 top plate was replaced with a 1.7-in. thick section in the casting to maintain equivalent ballistic properties.

Cast turret sections were subjected to numerous ballistic tests. One hundred and thirteen rounds were used on the rear half turret and about

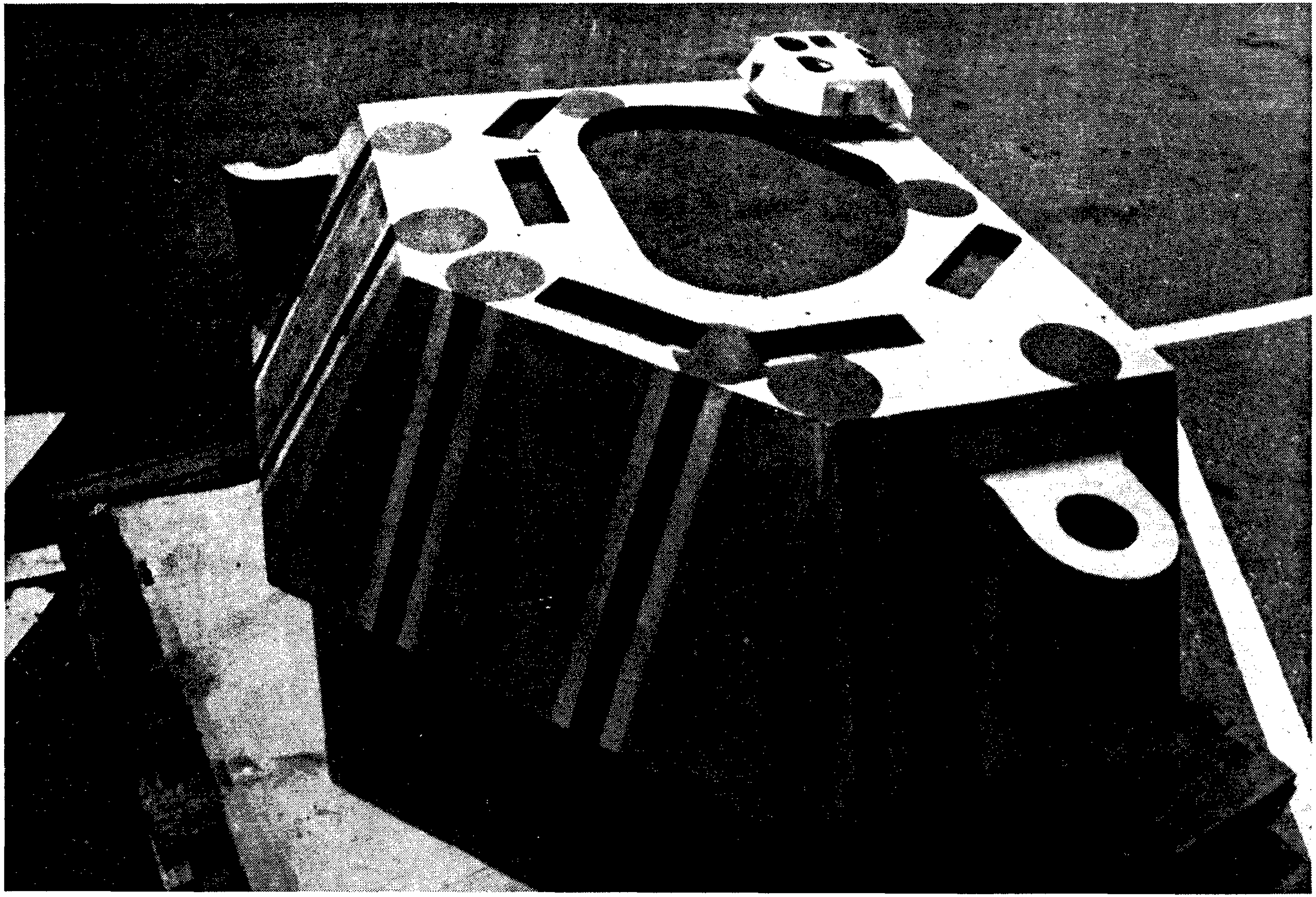


Figure 7 Overall View of the Rear Right-hand Quarter Casting. (Note the stripes indicating gates and risers of contacts.)

Figure 8

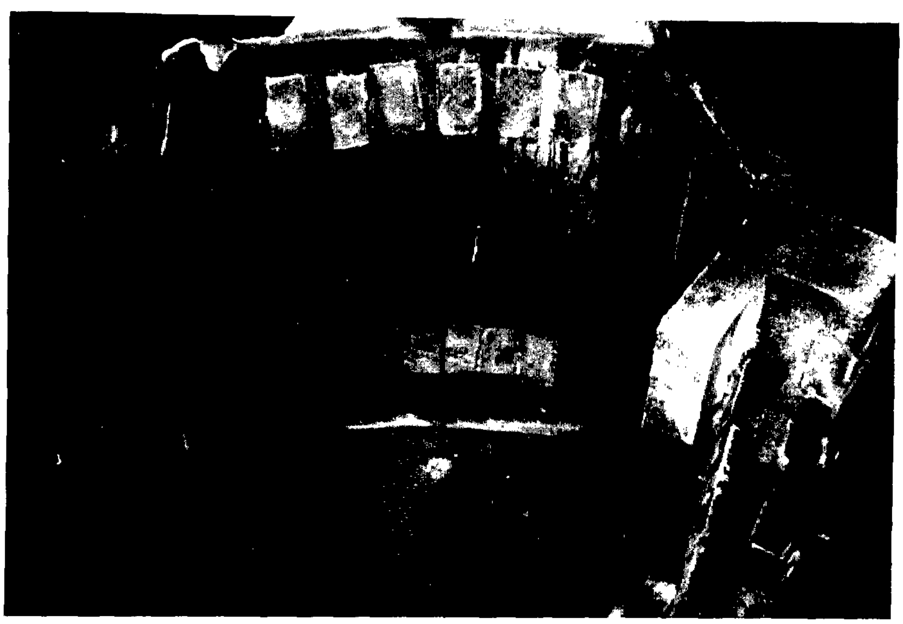


Figure 9 1/8 Section, Full Scale Cast Turret Piece Showing Risers and Chills.

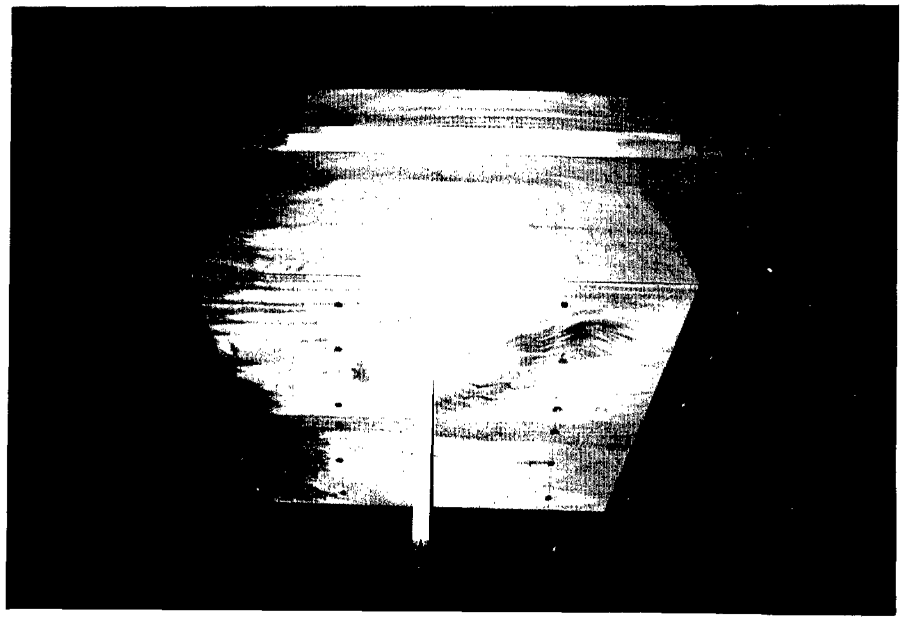


Figure 10

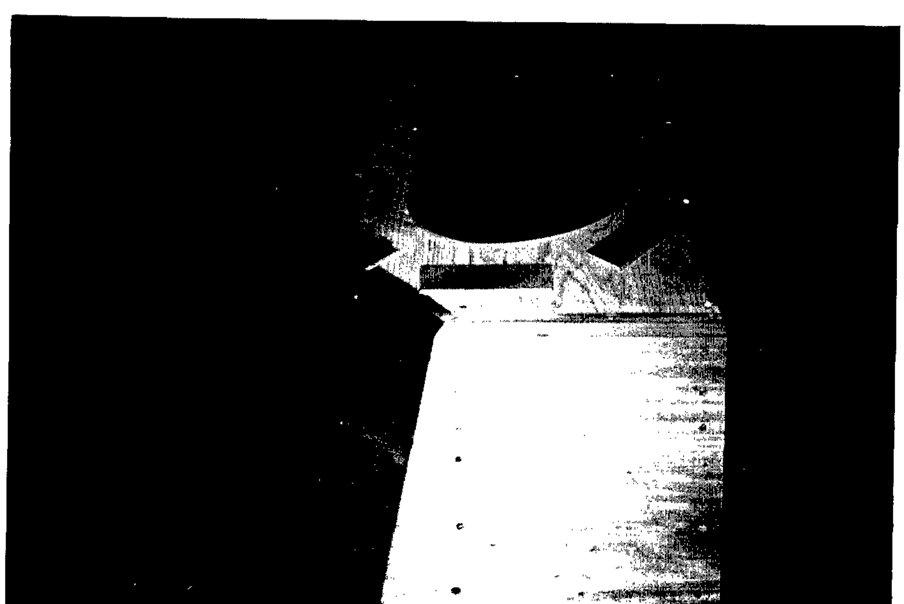


Figure 11 Pattern Rear Quarter Turret shown Unmounted Without Runners, Gates and Risers.

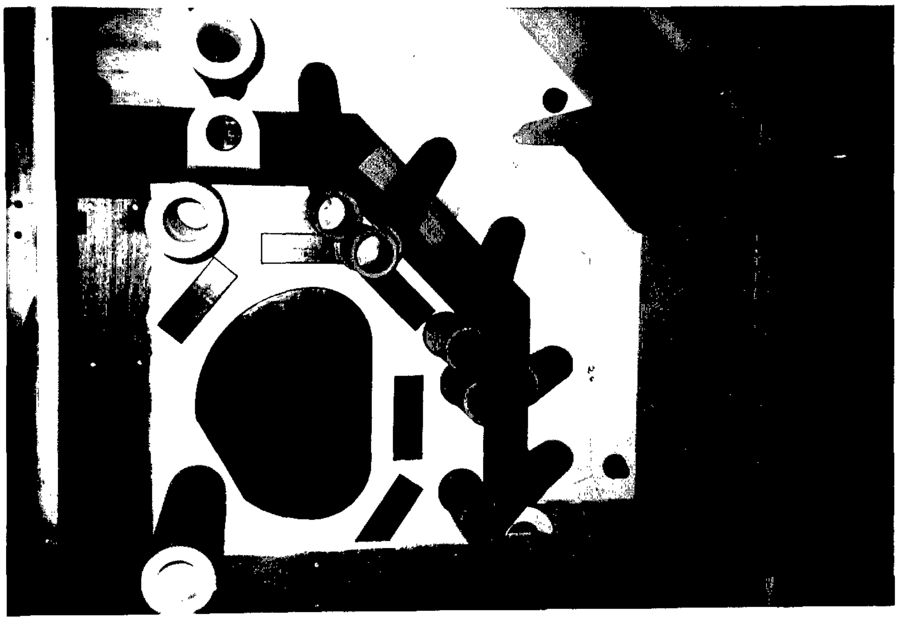


Figure 12

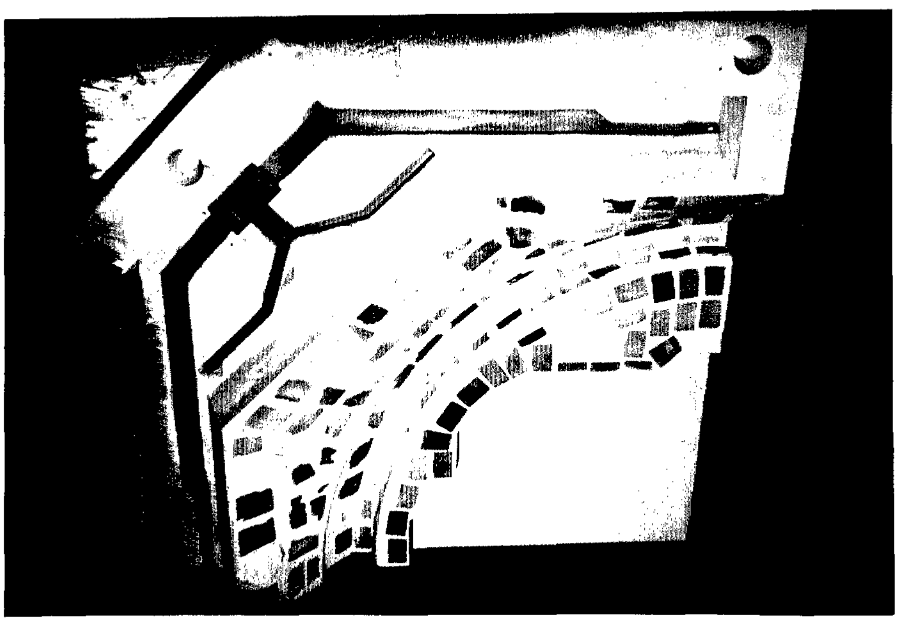


Figure 13 Drag Pattern of Rear Quarter Casting. (Note the insulated side feed risers, runners, core prints and feed system for smooth flow of hot metal.)

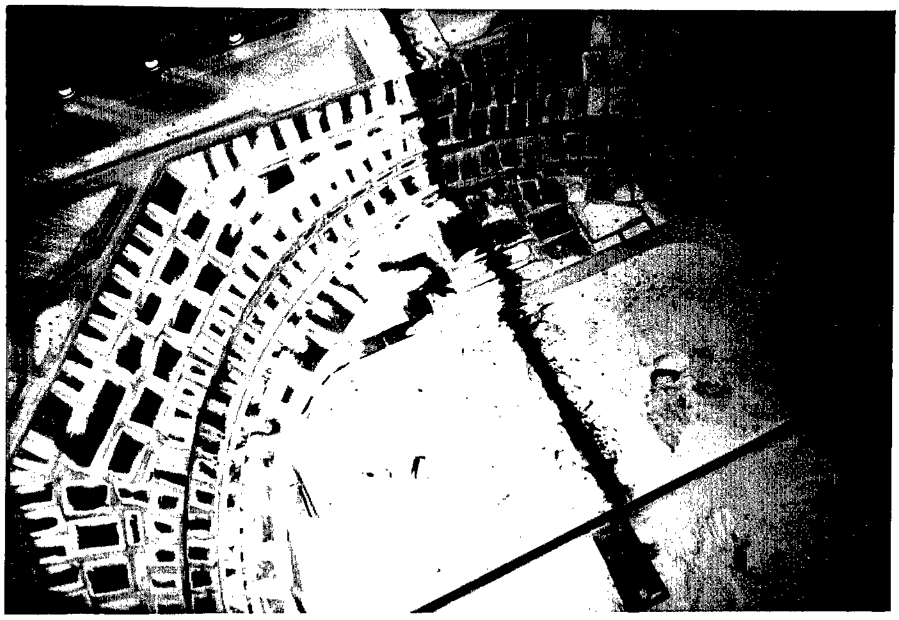


Figure 14 Chills were Located All Along the Surface for Chilled Areas and to Provide for Directional Solidification.

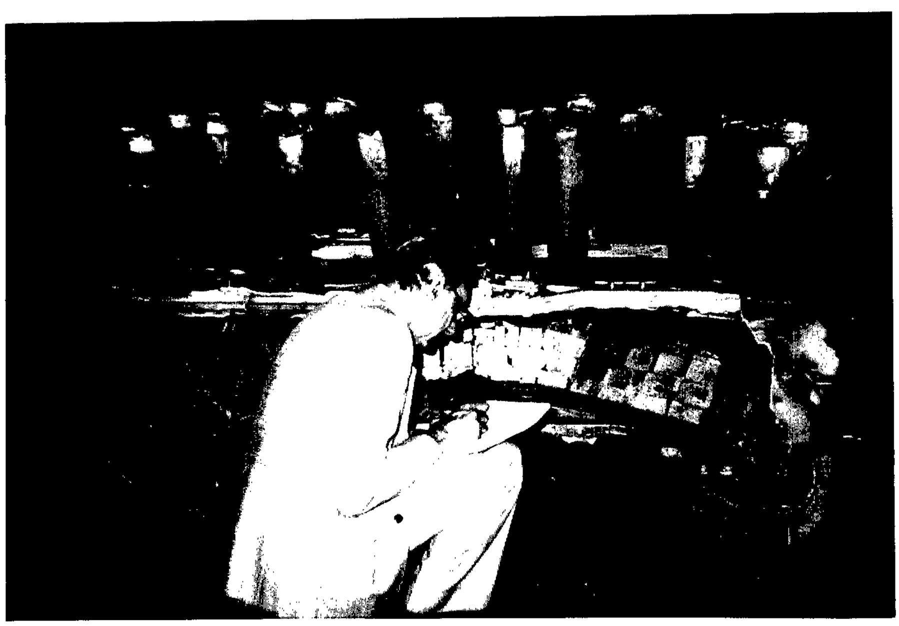


Figure 15 Rear Half Turret Casting Shown After Sand Shock Out and Prior to Removal of Gates and Risers.

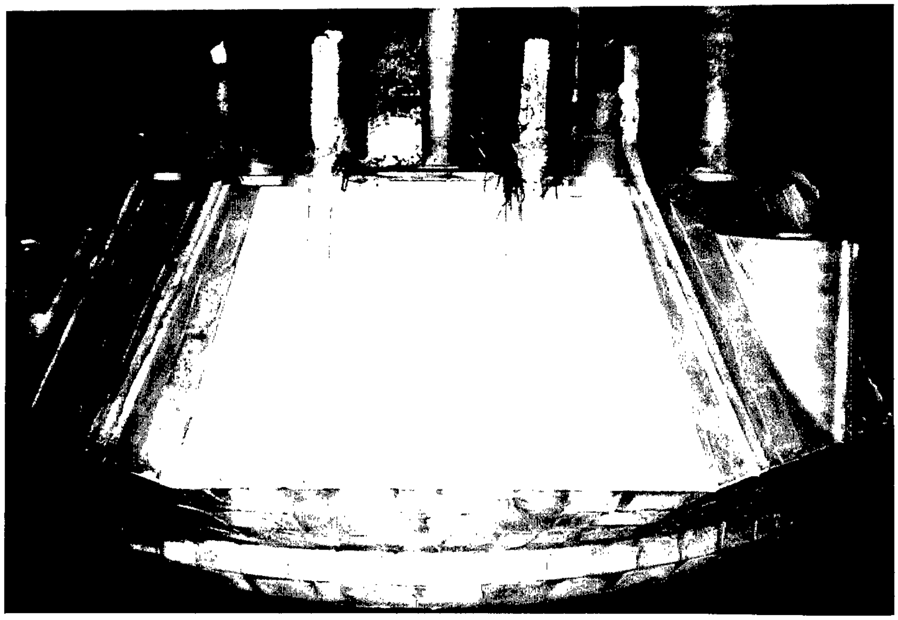


Figure 16 Casting With Runners and Side Risers Removed.

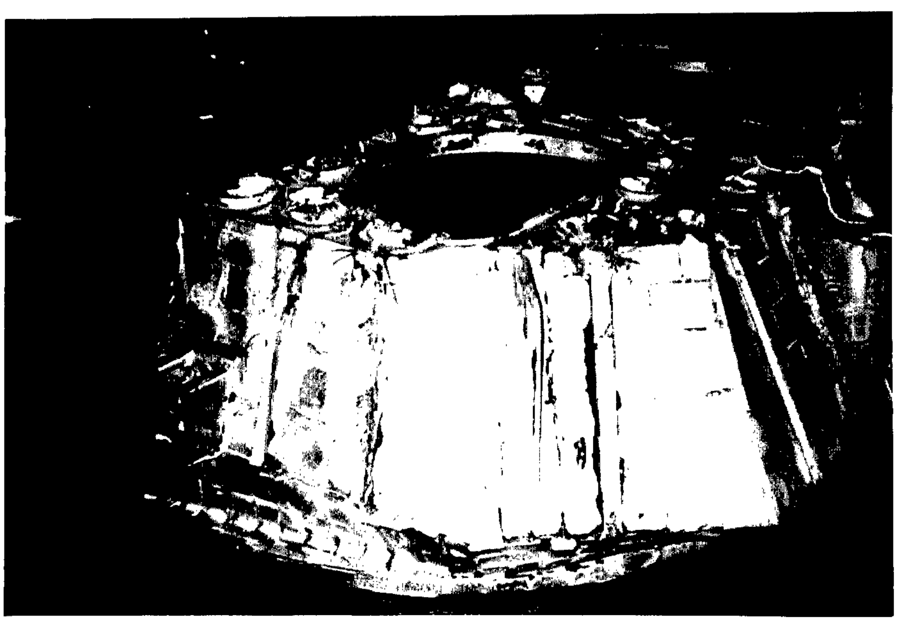


Figure 17 Rear Half of Turret Casting Prior to Final Clean Up.

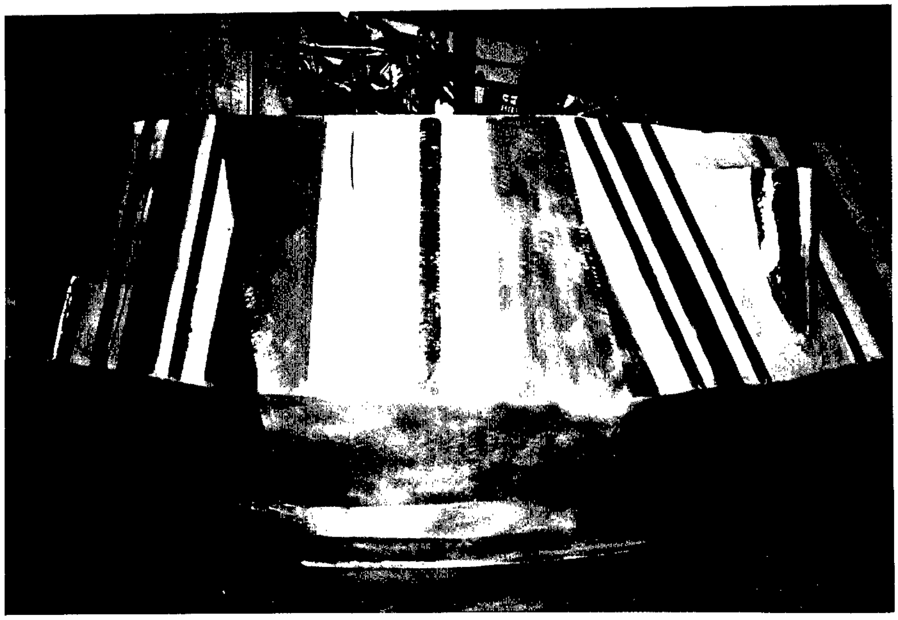


Figure 18 Finished Rear Half Casting. (Blue stripes denote chilled areas, red stripes denote unchilled feed areas.)

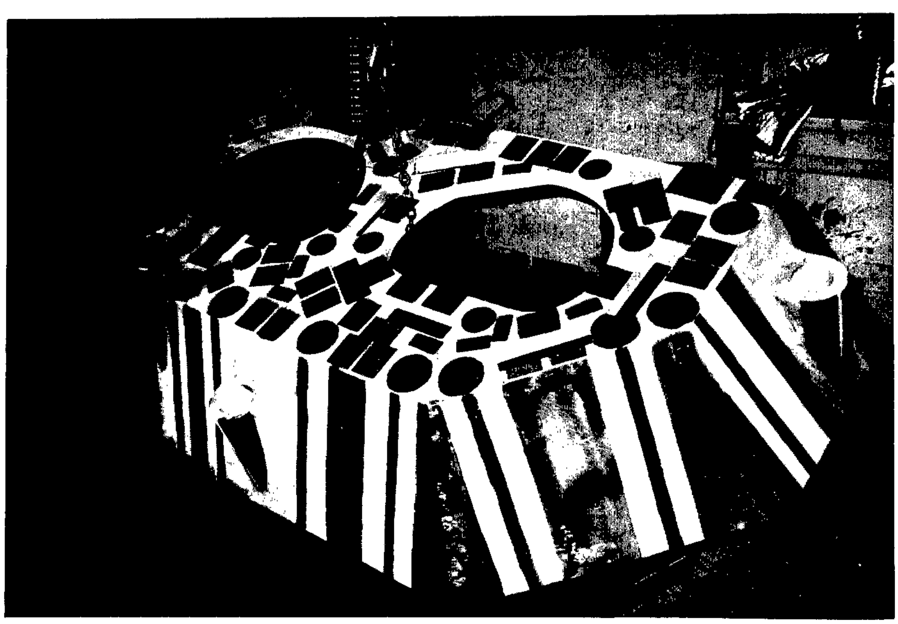


Figure 19 Top View of Finished Rear Half Casting. (Red dots denote riser contact areas.)

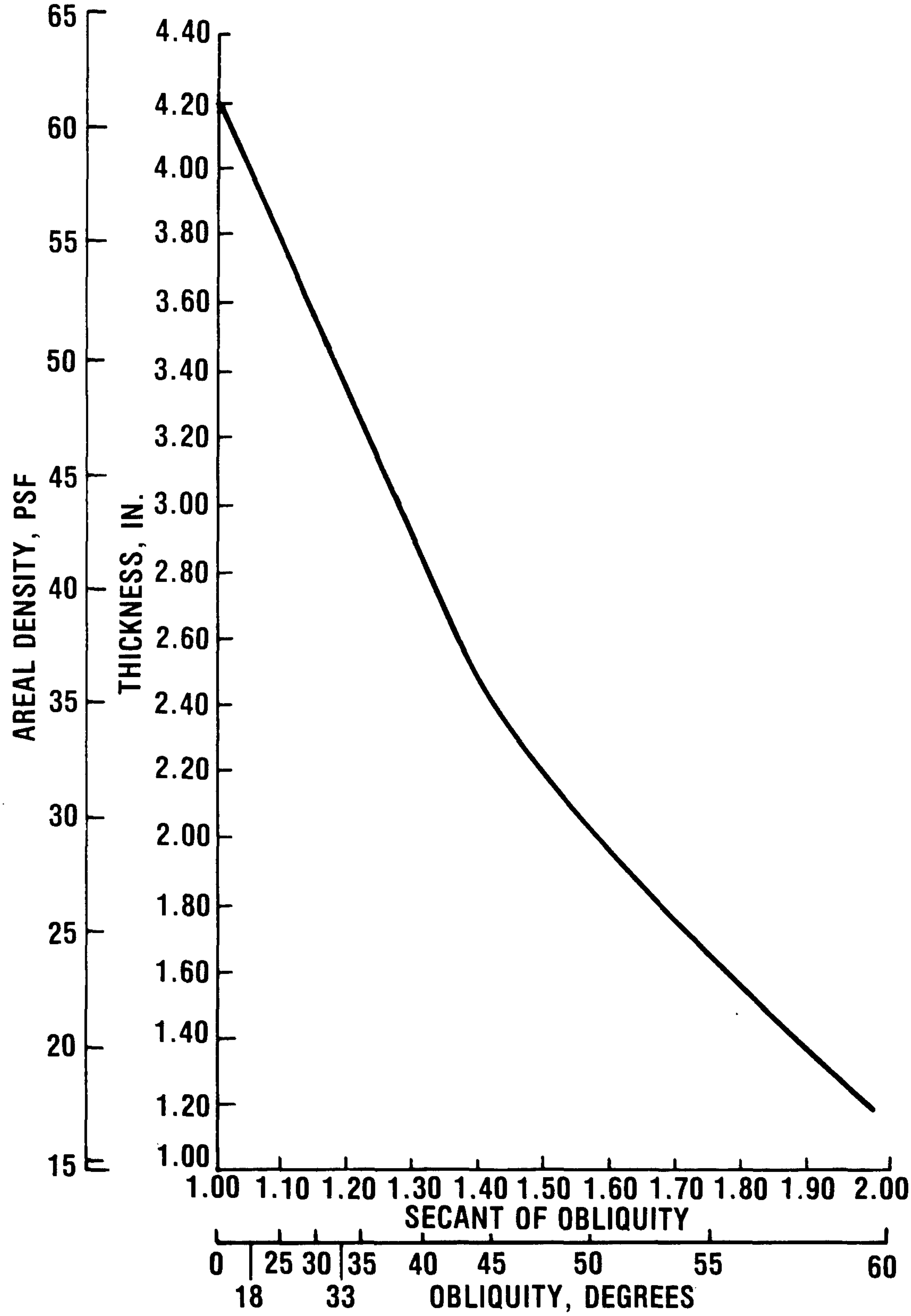


Figure 20 A206 Armor Design Curve.

half as many on rear quarter section. These tests on cast turret sections, using KE rounds, helped define a thickness versus obliquity curve for A206-T4 to provide protection equivalent to 7039 alloy under (AP) munitions threat. This A206 armor design curve (Figure 20) was generated using information from two V_{50} values obtained from shooting certain plate areas and using the classified publication "Ballistic Technology of Lightweight Armor - 1979 (U)" (AMMRC TR 79-10, Feb 1979 author's ref.).

This curve has been extrapolated to 95% protection. Ballistic test results of rear cast sections, as plotted on Figure 21, validate this relation (PP = Partial Penetration; CP = Complete Penetration). This curve was later modified to allow smaller wall thicknesses at higher obliquity. Some plate areas in the rear half casting failed because final cast thicknesses were below thicknesses specified by the curve. None of the plates with thicknesses and obliquities on and above the curve failed.

Other aspects of the ballistic testing and the conclusions are included in Appendix B (Confidential).

The results obtained from ballistic tests of cast aluminum plates were used in designing the turret sections, and the results obtained from testing of the quarter section castings were used to refine the pattern for the rear half turret.

Rear half turret test results will provide a guideline for designing the front half turret of Phase II.

3.1.5 Mechanical Tests

To establish relationships between mechanical properties, ballistic properties, and chemical composition of casting alloys, tensile tests were run on test samples drawn from cast plates and cast turret sections. As commonly understood, mechanical properties should be directly related to ballistic limits of the alloys. But, as it turned

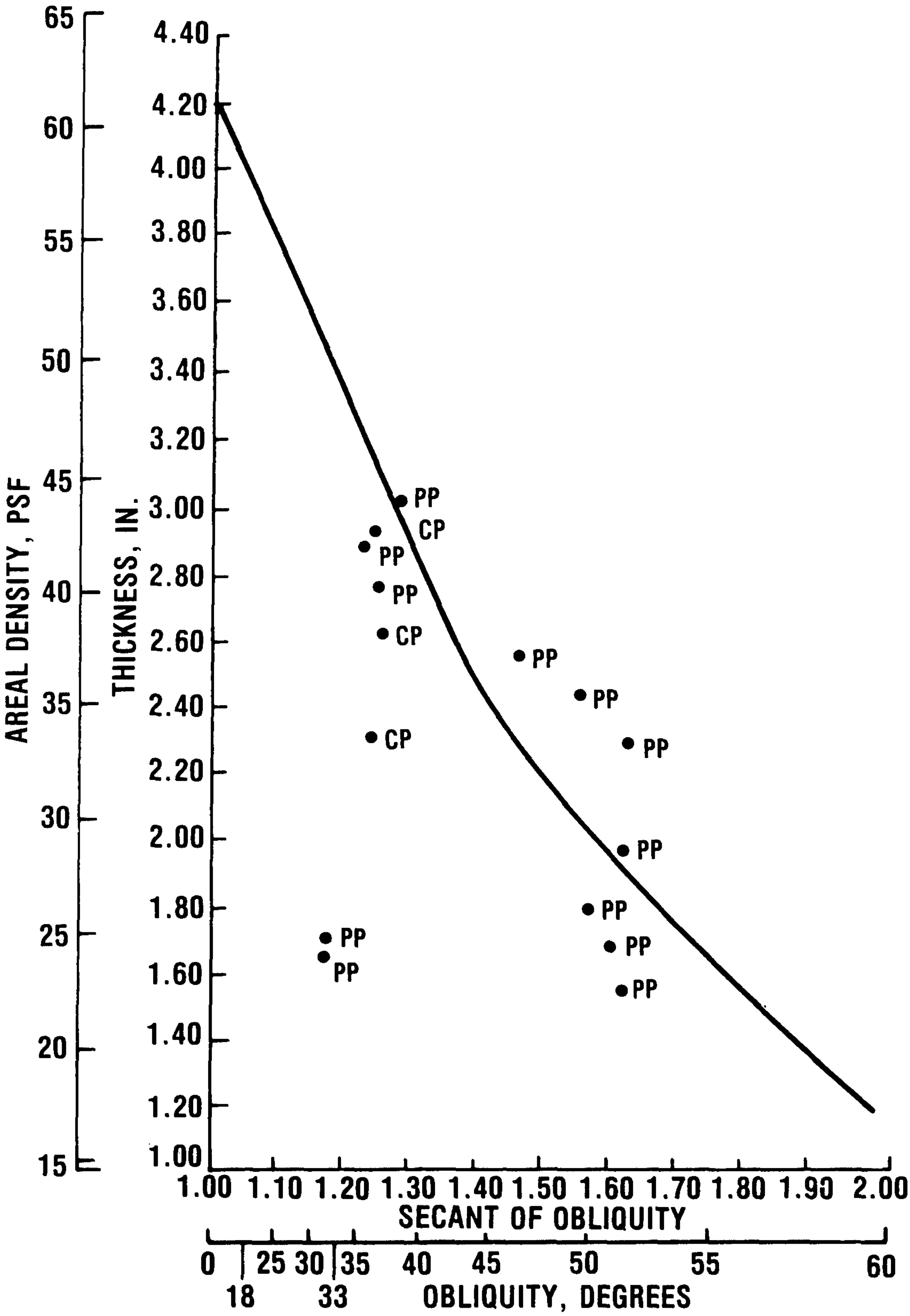


Figure 21 Ballistic Test Results of Rear Cast Turret Sections.

out, mechanical properties did not seem to significantly affect the ballistic properties of the material in this alloy. Plates with comparatively lower tensile strength were equally good ballistically.

Mechanical properties varied with chemistry and heat treatment, and both mechanical and ballistic properties changed between chilled and unchilled areas of the turret plates. A206-T7 had a greater variation in tensile strength and percentage of elongation between chilled and unchilled areas than did A206-T4. In a typical series of tests, chilled regions heat treated to the T7 condition gave an average tensile strength of 59.3 KSI (409 MPa) and an average elongation of 5.3%. Unchilled regions in the T7 condition had an average tensile strength of 38.4 KSI (265 MPa) and very low percentage of elongation. The variation in tensile strength between chilled and unchilled regions was, therefore, 20.9 KSI (144 Mpa). In the T4 condition, the variation in tensile strength was 4.5 KSI (50 MPa.).

Mechanical properties also varied with thickness. Test samples drawn from material near the plate surface showed higher tensile strengths than those drawn from the core area of the plates.

3.1.6 Tests for Susceptability to Intergranular Corrosion and Stress Corrosion Cracking (SCC)

The purpose of this test was to determine whether A206 casting alloy in T4 or T7 conditions (as received from the foundry) will meet Federal Test Requirements for stress corrosion cracking. Test samples were machined into C-ring test coupons (per ASTM G38-73) and stressed to 75% of their yield strengths. The samples were tested for 30 days (720 hours) in an alternate immersion test environment, using 3.5% salt water solution (per ASTM G44-75). All samples passed the C-ring test (i.e., no cracking detected) although some pitting occurred. Figure A-2 in Appendix A shows an overall view of a representative C-ring test sample after completion of test.

3.1.7 Metallurgical Tests

Metallurgical tests were performed to establish the heat treatment procedure to maximize mechanical properties. Photomicrographs of the microstructures of actual cast plates and turret sections, heat treated to T4 and T71, were analyzed. The following observations were made:

- The alloy in T71 heat threatment condition contains more precipitate than in the T4 condition. This is due to the overaging involved in the T7 heat treatment. Properties tend to stabilize during overaging.

- In the T71 condition there was an appreciable difference in grain size between the chilled and the unchilled areas. The difference in tensile strength between the two conditions was about 21 KSI (145 MPa).

- In the T4 condition there was no appreciable difference in grain size between the chilled and unchilled areas. The difference in the tensile strength was about 5 KSI (34. MPa).

3.1.8 Chemical Analysis

Chemical analysis of a representative plate A206 was made to determine if it met the limits of Aerospace Material Specifications AMS4236. It did conform to percentages by weight, determined by spectrographic methods in accordance with Federal Standard Methods No. 151 and Method No. 112. Appendix A, Table A-3, shows the chemical analysis of test samples.

3.2 Turret Casting In One-piece vs Several Pieces

Most of the existing foundries pouring aluminum are limited by the size of the castings they can pour or by the size of the castings they can solution heat treat.

To permit maximum flexibility for the contractor to select vendors and to allow maximum competitive pricing capability, it was proposed that the casting be split into two or more pieces. These pieces were to be welded together before final machining.

Merits and demerits of each alternative were evaluated and, finally, a one-piece casting was considered to be the best choice.

One-piece castings need no welding other than weld repairs and welding few brackets. This will eliminate edge preparation and costly weld fixtures. Elimination of weld fixtures, in turn, will free costly shop space and use of handling facilities. One-piece castings will eliminate shop control required for the handling, identifying, and storing of smaller castings. Above all, with a one-piece casting, the integrity of the unit is preserved. As many as 9 foundries have offered to cast and heat treat the turret in one piece (see Appendix D for a detailed study).

3.3 Preliminary Weight Study

An initial weight study estimated a 10% increase in the weight of the cast turret over the welded version. This result was based on a study of ballistic properties of 7039 and 5083 armor aluminum alloy in comparison to A206 alloy. It was estimated that A206 alloy requires, on an average, 10% additional wall thickness to resist an AP attack than does 7039. Figure 5 presents this relationship. This relationship was verified by subsequent ballistic tests on various cast plates and cast turret sections for .30 cal. AP attack.

Additional tests on cast sections under KE attack helped define a thickness versus obliquity relationship for A206-T4 for protection against KE type munitions. This curve indicated additional thickness for A206-T4 to match protection of 7039 alloy and, hence, further increase the weight of the casting. To limit this increase, three approaches were used:

1. Wall thickness was varied in relation to obliquity over the same plate area. The casting process offers the opportunity to vary thickness in proportion to obliquity which is not possible in the welded plate turret. This approach helped reduce thicknesses of plates in some areas.

2. Wall thicknesses were reduced in areas which are not exposed to outside threats. Excessive machining cost was the reason why some of the welded plates were kept thicker than necessary. The base plate has been reduced in thickness at various places.

3. Most important of all, weight savings resulted from additional use of spaced steel armor. Ballistic test results indicated that for the same protection the use of spaced steel armor proved to be the most weight-efficient. Figure 22 represents one of the weight reduction techniques used.

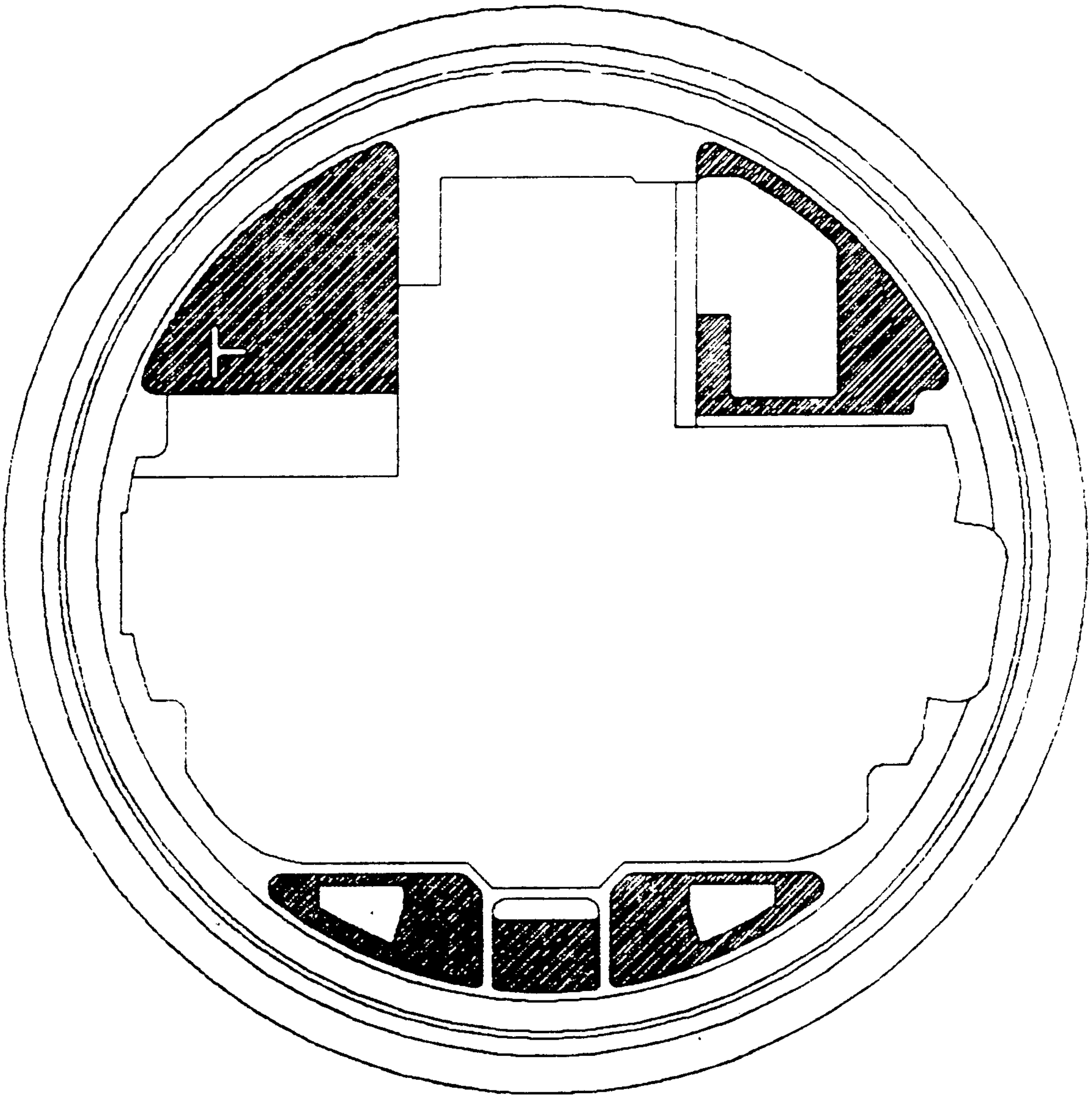
As a result of these weight saving measures, the net percentage increase in the weight of the casting over the welded turret, is expected to be less than 10%

3.4 Preliminary Cost Estimate

At this point, when the program is in its initial stage and only half casting has been developed and tested, it is too early to forecast the cost of the final casting.

Even at today's prices, comparable cost indicators point toward a lower cost for the cast version. Recent inquiries from various foundries, plus the increasing cost of the welded version, suggest an even more favorable cost for casting as opposed to welding.

The welded plate turret is extremely labor oriented. Due to continually increasing cost of labor, the welded turret cost is expected to rise more steeply than the cast turret cost. The differential cost is, therefore, expected to increase.



Recessed Areas (486.5 sq. in.),
Total Weight Savings, 37 lb.

Figure 22 Cast Turret Program Weight Reduction — Recessed Area.

4.0 REFERENCES

1. A. L. Kearney and J. Raffin, "Mechanical Properties of Aluminum Castings Alloys X206.0-T4 and XA206.0-T7", paper presented at American Foundrymen's Society 81st Casting Congress, Cincinnati, Ohio, April 26, 1977.

2. "Ballistic Technology of Lightweight Armor - 1979 (U)", AMMRC TR 79-10, February 1979.

APPENDIX A

METALLURGICAL TESTS

Series I — Cast Aluminum Plates

OBJECTIVES

To investigate the metallurgical integrity of A206 cast aluminum plates for potential use in the cast turret program.

BACKGROUND

Four A206 aluminum plates were submitted for testing. The test program undertaken on these plates is shown in Table A-1. All tests were duplicated for the chilled and unchilled areas of each plate.

TABLE A-1 TEST PROGRAM SUMMARY

Plate Number	Condition	Thickness		Number Tests Performed*			
		Inches	mm	Metallography	Stress Corrosion	Tensile	Chemical Analysis
A	– T71	1.995	50.673	2			
C	– T71	1.552	39.42	2	18	6	
D	– T4	1.555	39.555	2	18	6	
E	– T71	0.858	21.793				1

*Numbers denote samples tested and include both chilled and unchilled specimens.

Introduction

Four plates were received for mechanical and metallurgical testing.

Plate A: Plate size 1.995 in. x 18 in. x 36 in.; machined on both sides; casting alloy A206; solution heat treated to T71.

Plate C: Plate size 1.552 in. x 18 in. x 36 in.; machined on both sides; casting alloy A206; solution heat treated to T4.

Plate D: Plate size 1.555 in. x 18 in. x 36 in.; machined on both sides; casting alloy A206; solution heat treated to T71.

Plate E: Plate size 0.858 in. x 18 in. x 36 in.; machined on both sides; casting alloy A206; solution heat treated to T71.

RESULTS

Six specimens (three chilled, three unchilled) from plates C and D were submitted for tensile testing. Table A-2 lists the mechanical properties determined from the tests. A typical fracture face is shown in Figure A-1.

Eighteen samples (nine chilled, nine unchilled), again from plates C and D, were tested for susceptibility to stress corrosion cracking. These samples were machined into C-Ring test coupons (per ASTM G38-73) and stressed to 75% of their yield strengths. The samples were tested for 30 days (720 hours) in an alternate immersion test environment, using 3.5% salt water solution (per ASTM G44-75). All samples passed the C-Ring test (i.e., no cracking detected) although some pitting took place (see Figure A-2).

Metallographic samples of chilled and unchilled areas of A206 alloy in the −T4 and −T71 conditions were prepared. Figures A-3 through A-6 show the representative microstructures of these areas.

Chemical analysis of a representative plate met the limits of AMS 4236 (A206) (see Table A-3).

OBSERVATIONS

The following observations were made of the microstructures seen:

- The plate in the −T71 condition contains more precipitate than the plate in the −T4 condition. This is due to the overaging involved in the −T71 condition.
- In the −T71 condition, there was an appreciable difference in grain size between the chilled and unchilled areas. The difference in tensile strength between these two areas was 20.9 ksi (144.1 MPa).
- In the −T4 condition, there was no appreciable difference in grain size between the chilled and unchilled areas. The difference in tensile strength was 4.5 ksi (31.06 MPa).

TABLE A-2 TENSILE TEST RESULTS

Plate Number	Thickness (Inches)	Condition	Area	Tensile Strength, KSI (MPa)	Yield Strength, KSI (MPa)	Percent Elongation (in 2 In.)
C	1.552	– T71	Chilled	60.6 (417.82)	51.8 (357.1)	5.5
				60.5 (417.13)	50.8 (350.25)	6.0
				56.9 (392.31)	49.4 (340.60)	4.5
			(Average)	59.3 (408.86)	50.7 (349.56)	5.3
			Unchilled	37.6 (259.24)	—* —	0.2
				38.2 (263.38)	—* —	0.2
				39.5 (272.34)	—* —	0.2
			(Average)	38.4 (264.76)	— —	0.2
D	1.555	– T4	Chilled	47.1 (324.74)	39.1 (269.58)	5.0
				48.3 (333.01)	38.5 (265.45)	5.5
				41.7 (287.51)	37.5 (258.55)	3.0
			(Average)	45.7 (315.09)	38.4 (264.76)	4.5
			Unchilled	45.8 (315.78)	38.8 (267.52)	5.0
				37.1 (255.8)	35.0 (241.32)	2.0
				40.6 (279.93)	36.0 (248.21)	3.5
			(Average)	41.2 (284.06)	36.6 (252.35)	3.5

*Sample failed prior to yielding.

TABLE A-3 CHEMICAL ANALYSIS CAST ALUMINUM ALLOY A206

(WEIGHT %)

Element	Plate	AMS 4236
Cu	4.55	4.20/5.00
Mn	0.29	0.20/0.50
Mg	0.37	0.15/0.35
Ti	0.12	0.15/0.30
Fe	0.05	0.10 Max.
Zn	0.03	0.05 Max.
Si	0.03	0.05 Max.
Ni	—	0.05 Max.

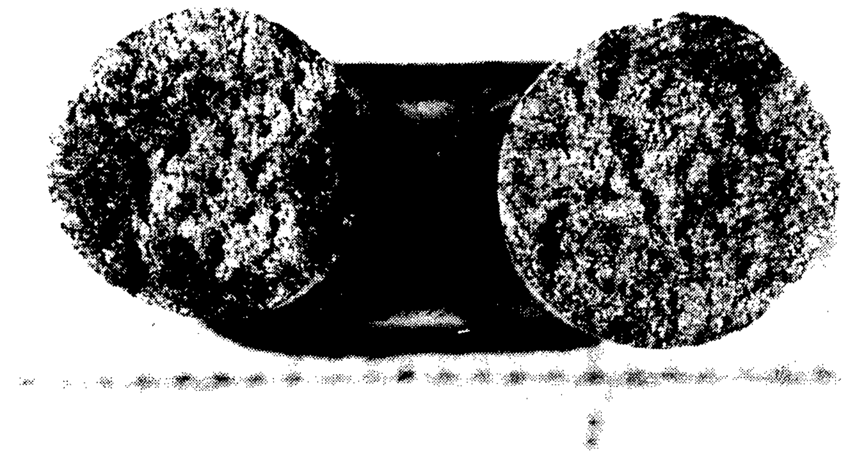


Figure A-1 Representative Tensile Specimen Fracture Faces Unetched

1.5X

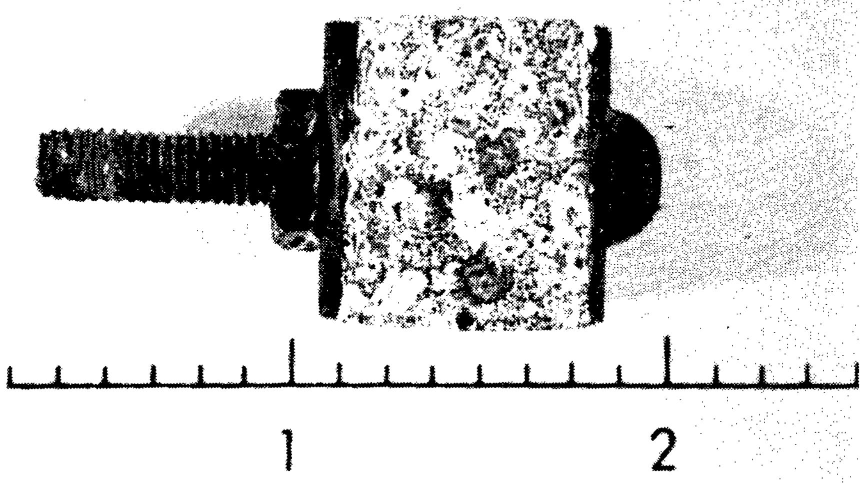


Figure A-2 Representative C-Ring Test Sample After Completion of Test

(No cracks were noted. Note pitting of test surface. Black coating on remainder of surface is to prevent galvanic corrosion between specimen and stressing bolt.)

1.5X

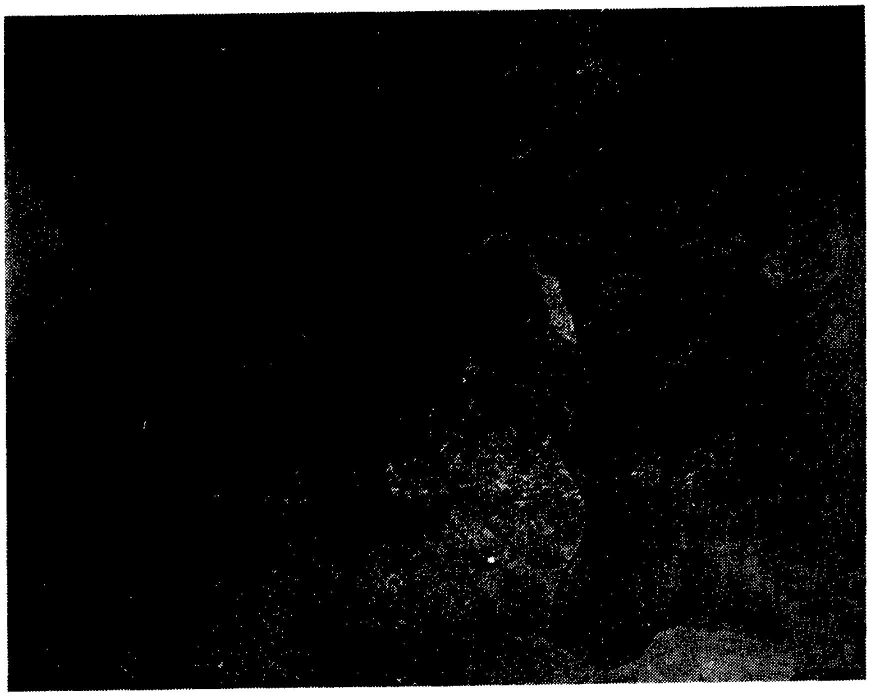


Figure A-3 Photomicrograph of Plate C

(Condition of sample: – T71, unchilled. Structure consists of Cu_2FeAl_7 (medium grey blades) and some particles of silicon (dark grey)).

Etchant: Keller's Reagent 100 ×

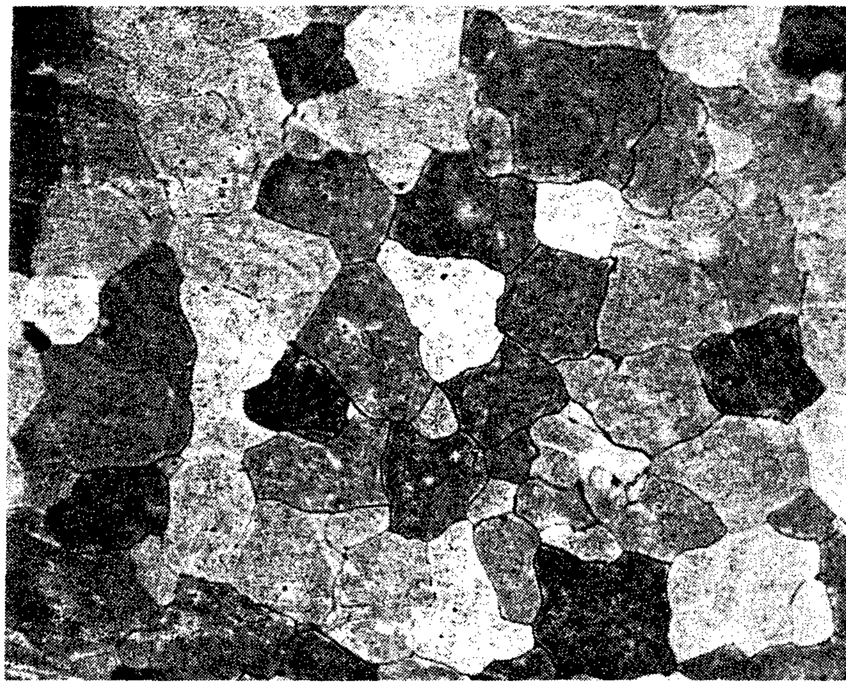


Figure A-4 Photomicrograph of Plate C

(Condition of sample: – T71, chilled. Note difference in grain size from Figure A-3. Structure is the same as Figure A-3.)

Etchant: Keller's Reagent 100×

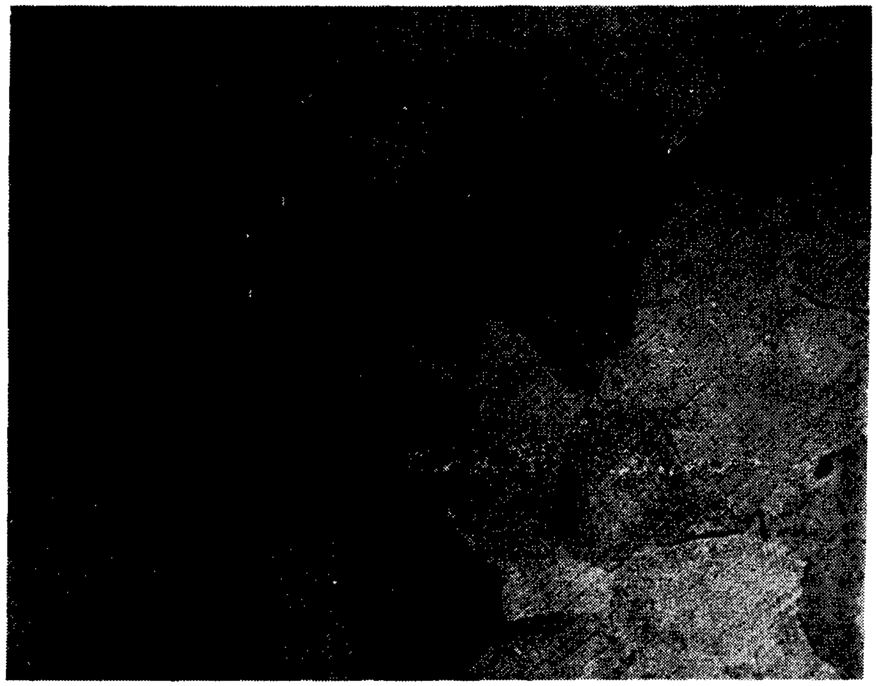


Figure A-5 Photomicrograph of Plate D

(Condition of sample: – T4, unchilled. Structure is the same as Figure A-3. Note less precipitate due to no overaging (as in Figures A-3 and A-4.))

Etchant: Keller's Reagent 100×

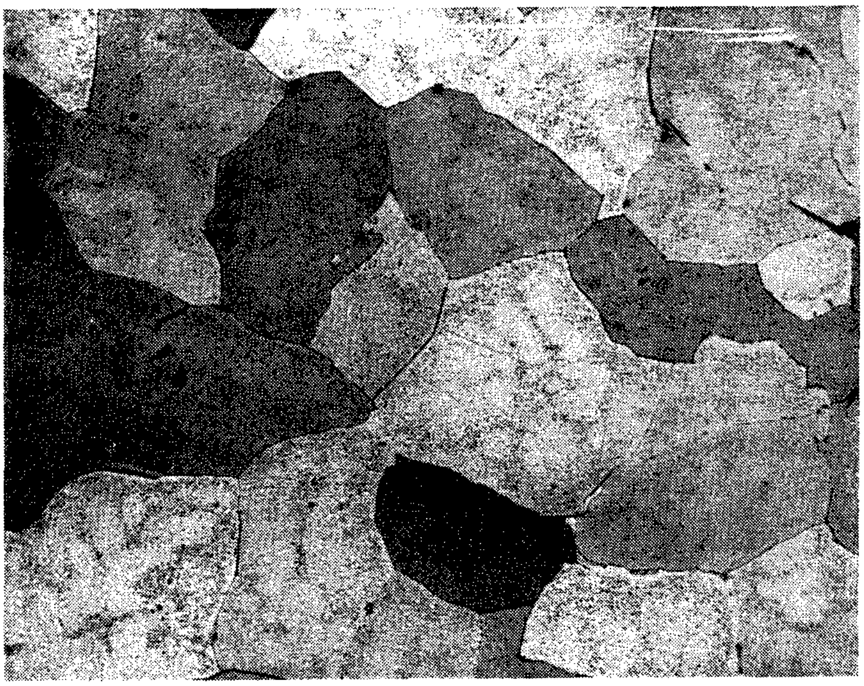


Figure A-6 Photomicrograph of Plate D

(Condition of sample: – T4, chilled. Note little change in grain size from Figure A-3.)

Etchant: Keller's Reagent 100 ×

METALLURGICAL TESTS

Series II — Rear Right-hand Quarter Turret Casting

OBJECTIVE

To determine the tensile properties of specified areas of the cast aluminum A206-T4 IFV turret.

BACKGROUND

This investigation constitutes CEL's second series of tests in the cast turret program. A full scale, quarter section of the IFV turret was cast. The test program undertaken on this casting is shown in Table A-4. All tests were repeated for the chilled, unchilled and transition areas of each segment of the quarter casting.

TABLE A-4 MECHANICAL TEST RESULTS

Area	Test Bar	Tensile Strength KSI	Tensile Strength (MPa)	Yield Strength KSI	Yield Strength (MPa)	% Elongation (in 2 inches)
Riser	D*	37.5	(258.5)	33.9	(233.7)	4.0
	E*	41.4	(285.4)	34.9	(240.6)	5.0
	L	37.0	(255.1)	32.4	(223.3)	4.0
	N	52.0	(358.5)	35.4	(244.0)	13.0
	O*	30.7	(211.6)	30.7	(211.6)	<0.5
	Q	38.1	(262.6)	32.3	(222.7)	5.0
	R	45.2	(311.6)	34.0	(234.4)	8.0
	Y	39.0	(268.9)	36.4	(250.9)	3.0
Average		42.3	(291.6)	34.1	(235.1)	6.6
Chill	J	44.5	(306.8)	38.2	(263.3)	4.0
	K	43.4	(299.2)	36.4	(250.9)	5.0
	M	42.2	(290.9)	41.4	(285.4)	4.5
	T	38.0	(262.0)	35.4	(244.0)	3.0
	U	41.3	(284.7)	36.8	(253.7)	3.0
	V*	24.7	(170.3)	24.7	(170.3)	<0.5
	W	49.5	(341.2)	37.1	(255.8)	8.0
Average		43.2	(297.8)	37.6	(259.2)	4.6
Transition	H	38.1	(262.6)	35.9	(247.5)	3.0
	I*	33.8	(233.0)	32.7	(225.4)	3.0
	P	39.2	(270.2)	35.9	(247.5)	3.0
Average		38.7	(266.8)	35.9	(247.5)	3.0
Edge of Chill	F	43.7	(301.3)	36.3	(250.2)	5.0
	G*	37.4	(257.8)	34.4	(237.1)	5.0
	S	44.3	(305.4)	39.6	(273.0)	3.0
	X	41.1	(283.3)	36.0	(248.2)	4.5
Average		43.0	(296.4)	37.3	(257.1)	4.2

*Porosity was noted on the fracture faces. These values were not included in the averaging of the results.

RESULTS

Twenty-two standard 0.500-in. (12.7 mm) diameter tensile specimens were prepared from specified locations in the turret sections received (see Figures A-7 through A-10). All specimens were removed from as near the surface of the casting as possible. Table A-4 lists the results of these tests. A summary of the test results is included in Table A-5.

Evidence of porosity was noted on the fracture surface of six specimens (D, E, G, I, O and V). Figure A-11 shows the worst case example of this. These specimens were from random locations throughout the sections received. All five were excluded from the averaging of the results, but were included in the listing of Table A-4.

Chemical analysis of a representative section of the cast turret met the requirements of AMS 4236 (A206-T4) with some minor exceptions (see Table A-6).

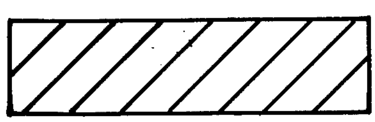
CONCLUSIONS

The average results from all four areas from the quarter turret casting failed to meet the tensile strength and elongation requirements of AMS 4236 (A206-T4). However, all four areas met the yield strength requirements of that specification.

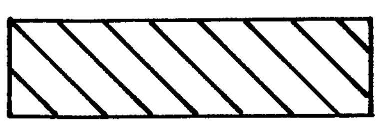
Location and Orientation of Test Bars

LEGEND

(Not to Scale)



— Chill Area



— Riser Area

Figure A-7

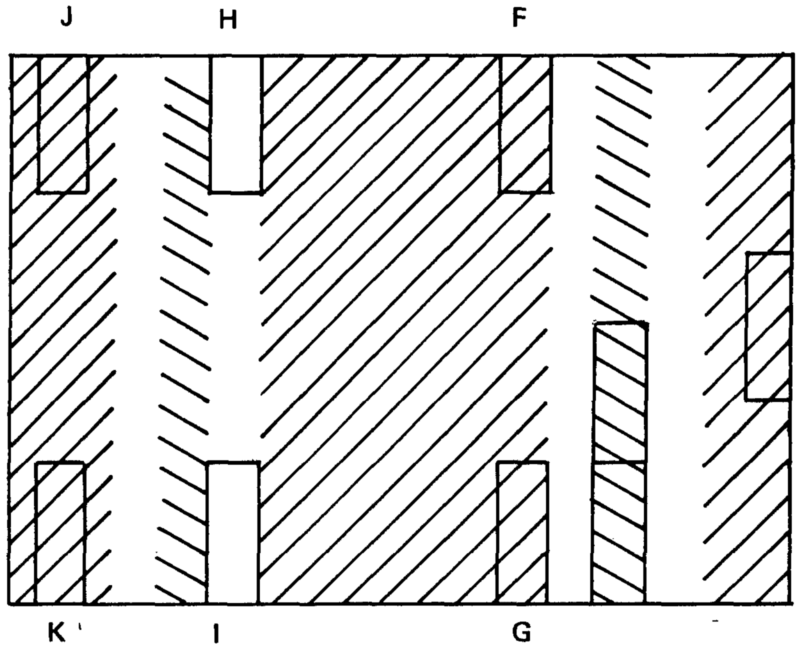


Figure A-8 Section No. 81088-11

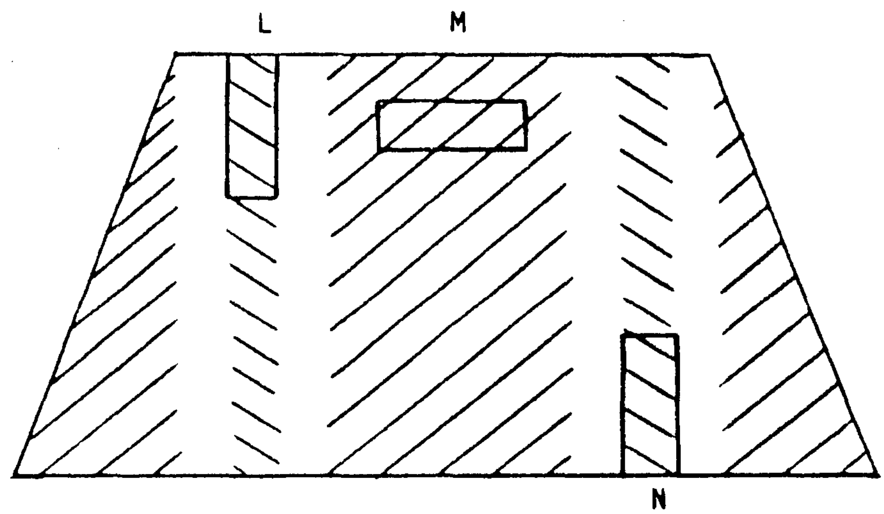


Figure A-9 Section No. 81088-2/81092

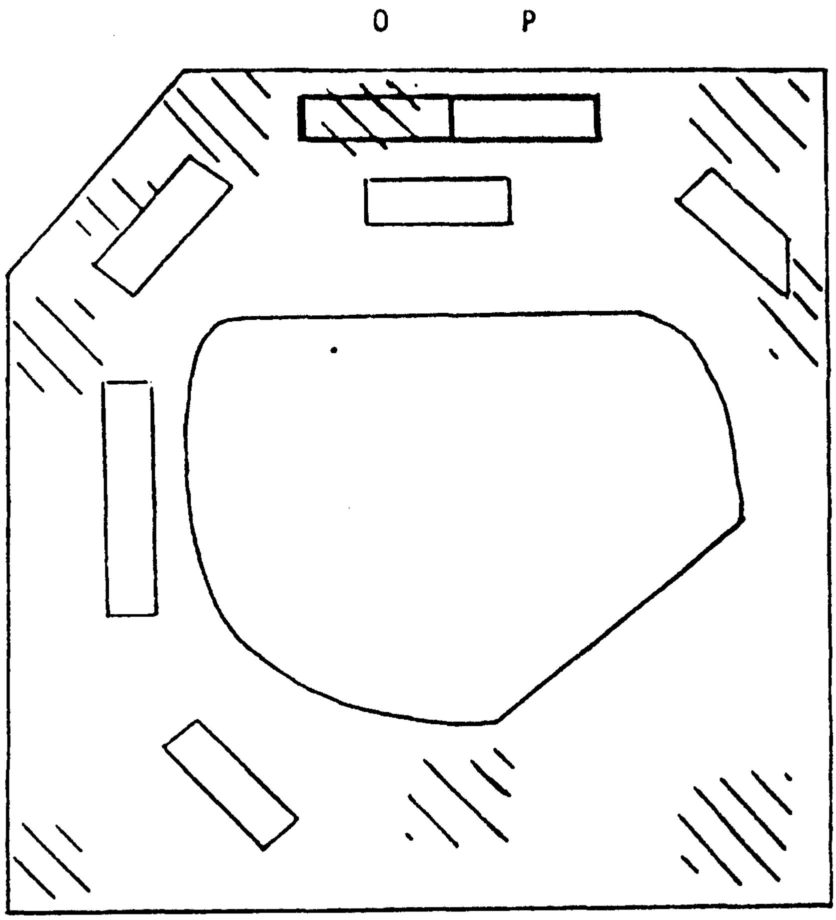


Figure A-10 Section No. 81069

TABLE A-5 SUMMARY OF MECHANICAL TEST RESULTS

Property	Chill Area	Riser Area	Transition Area	Edge of Chill Area	A206-T4 (as per AMS 4336)*
Tensile Strength (ksi)	43.2	42.3	38.7	43.0	45.0
Yield Strength (ksi)	37.6	34.1	35.9	37.3	26.0
% Elongation (in 2 inches)	4.6	6.6	3.0	4.2	8.0

*Minimum values for undesignated areas of a casting.

TABLE A-6 CHEMICAL ANALYSIS
(Weight %)

Element	Turret Section	A206.0 (per AMS 4236)
Cu	4.2	4.2/5.0
Mg	0.30	0.15/0.35
Mn	0.30	0.20/0.50
Ti	0.14*	0.15/0.30
Si	0.06*	0.05 Max
Ni	0.01	0.05 Max
Zn	0.03	0.10 Max
Fe	0.07	0.10 Max

*Does not meet requirements.

METALLURGICAL TESTS

Series III — Rear Half Turret Casting

OBJECTIVE

To determine the tensile properties and perform metallurgical examination of A206-T4 and A206-T7 cast aluminum alloys from specified areas of rear half and rear left quarter sections of the turret.

BACKGROUND

This investigation constitutes CEL Series II testing of the cast turret program. Full scale half and quarter sections of the turret were cast. Test samples were taken from near the surface areas and inner areas of the cast sections. The test program undertaken on these castings is shown in Table A-7. All tests were repeated for the chilled, unchilled and transition areas of each segment of the quarter casting.

RESULTS

Twenty standard 0.500-in. (12.7mm) diameter tensile specimens were prepared from specified locations in the turret sections received. Figures A-12 and A-18 show locations of test bars machined from cast turret sections. All specimens were removed from as near the surface of the casting as possible. The results of the test performed on the specimens are listed in Table A-7.

One specimen each from the chilled, risered, and transition zones of the two tempers present (–T4 and –T71) was cross-sectioned and examined metallographically.* The photomicrographs of these specimens are shown in Figures A-19 through A-23.

*No specimens were taken from a transition zone of the –T4 temper.

TABLE A-7 TENSILE TEST RESULTS

– T4, Chilled or Unchilled Specimens						
S/N	Condition*	Tensile Strength		Yield Strength		% Elongation (in 2 inches)
		KSI	(MPa)	KSI	(MPa)	
B	CH	53.9	(371.6)	40.9	(282.0)	8.0
C	UC	54.2	(373.7)	40.2	(277.1)	8.5
D	CH	55.1	(379.9)	40.7	(280.6)	9.0
L	CH	57.0	(393.0)	41.1	(283.3)	10.0
M	CH	52.4	(361.2)	40.6	(279.9)	6.5
R	CH	52.3	(360.6)	41.9	(288.8)	6.0
S	CH	50.9	(350.9)	39.6	(273.0)	7.5
U**	CH	40.9	(282.0)	38.8	(267.5)	2.5
Average		53.7	(370.2)	40.7	(280.6)	7.9
Required[1]		45.0	(310.2)	26.0	(179.2)	8.0

– T4, Risered Specimens						
S/N	Condition*	Tensile Strength		Yield Strength		% Elongation (In 4 Diameters)
		KSI	(MPa)	ksi	(MPa)	
A	R	39.5	(272.3)	34.6	(238.5)	4.0
K	R	43.1	(297.1)	38.0	(262.0)	3.5
N	R	42.5	(293.0)	38.9	(268.2)	3.0
O	R	40.6	(279.9)	39.9	(275.1)	2.0
P**	R	39.8	(274.4)	37.6	(259.2)	2.0
T	R	38.0	(262.0)	36.5	(251.6)	2.0
V**	R	41.3	(284.7)	37.4	(257.8)	4.0
Average		40.7	(280.6)	37.6	(259.2)	2.9
Required[1]		45.0	(310.2)	26.0	(179.2)	8.0

(Continued next page)

TABLE A-7 (cont'd)

– T71, Chilled Specimens						
S/N	Condition*	Tensile Strength		Yield Strength		% Elongation (In 4 Diameters)
		KSI	MPa	KSI	(MPa)	
E	CH	44.3	(305.4)	44.1	(304.0)	1.0
H	CH	46.6	(321.3)	***		0.2
Average		45.5	(313.7)	44.1	(304.0)	0.5
Required²		50.0	(344.7)	40.0	(275.7)	1.5

– T71, Risered Specimens						
S/N	Condition*	Tensile Strength		Yield Strength		% Elongation (In 4 Diameters)
		KSI	(MPa)	KSI	(MPa)	
G	R	37.9	(261.3)	37.6	(259.2)	2.0
I	R	41.0	(282.6)	***		0.2
Average		39.5	(272.3)	37.6	(259.2)	1.0
Required²		50.0	(344.7)	40.0	(275.7)	1.5

– T71, Transition Specimens						
S/N	Condition*	Tensile Strength		Yield Strength		% Elongation (In 4 Diameters)
		KSI	(MPa)	KSI	(MPa)	
F	T	46.7	(321.9)	41.0	(282.6)	4.5
Required²		50.0	(344.7)	40.0	(275.7)	1.5

*CH—Chilled, UC—Unchilled, R—Risered, T—Transition.

**Widespread porosity noted on fracture surface; values not used to compute average.

***Failed prior to yielding.

[1]Per AMS 4236, for aluminum alloy A206.0-T4 (solution heat treated and naturally aged), chilled and unchilled.

[2]Per AMS 4235, for aluminum alloy A206.0-T71 (solution heat treated and artificially aged), chilled and unchilled.

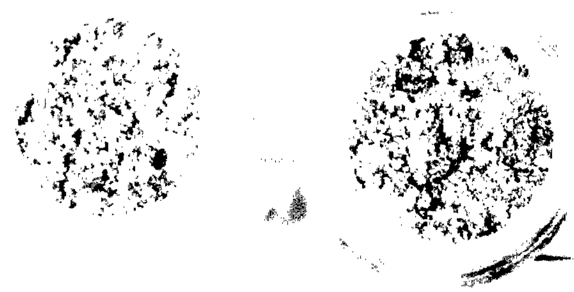


Figure A-11 Fracture Face of Specimen Showing Extensive Porositiy (darkened areas).

(A total of five specimens exhibited this.)

Unetched 2×

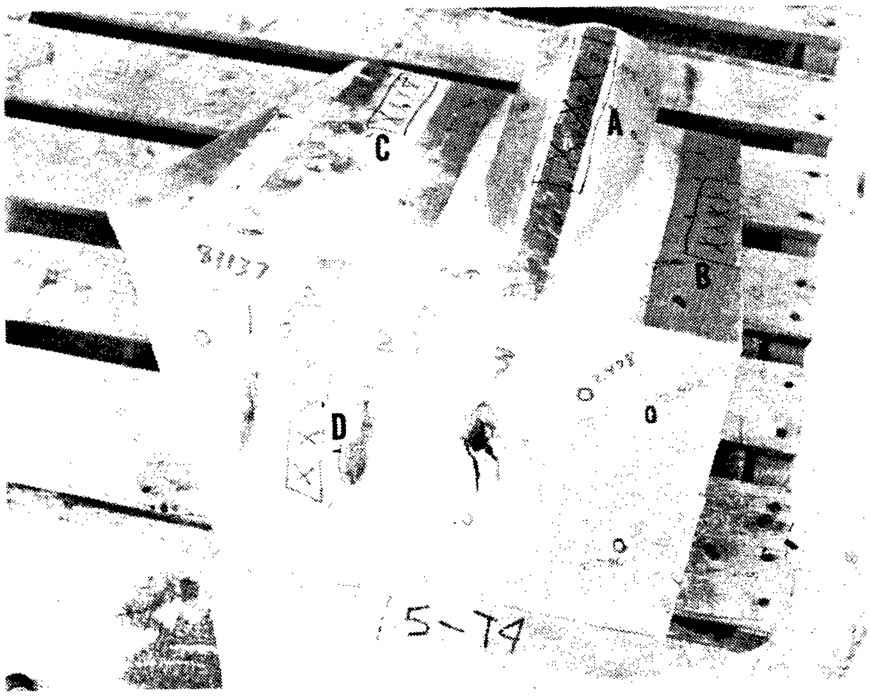


Figure A-12   Test Bars A, B, C, and D

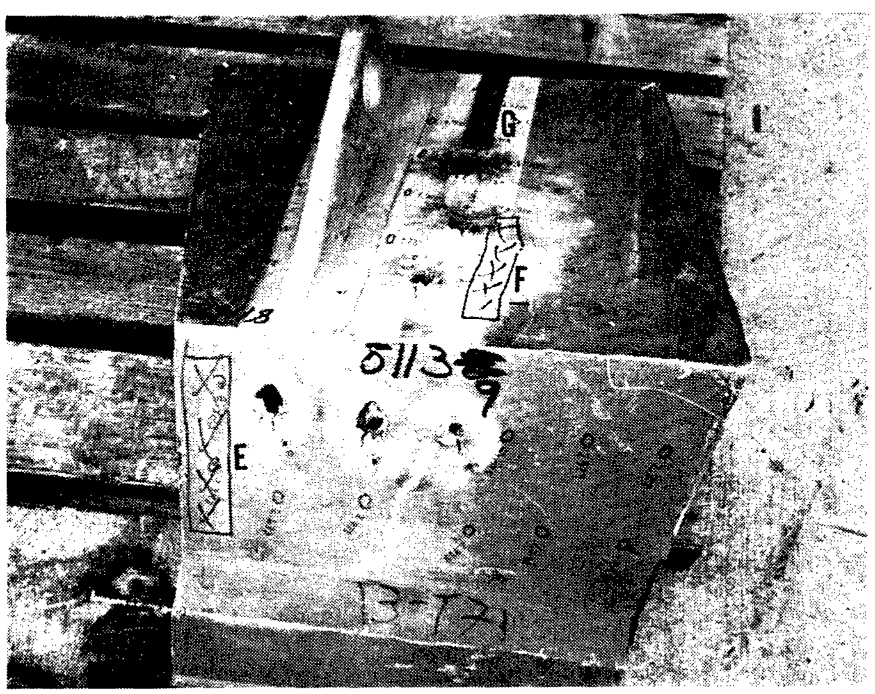


Figure A-13   Test Bars E, F, and G

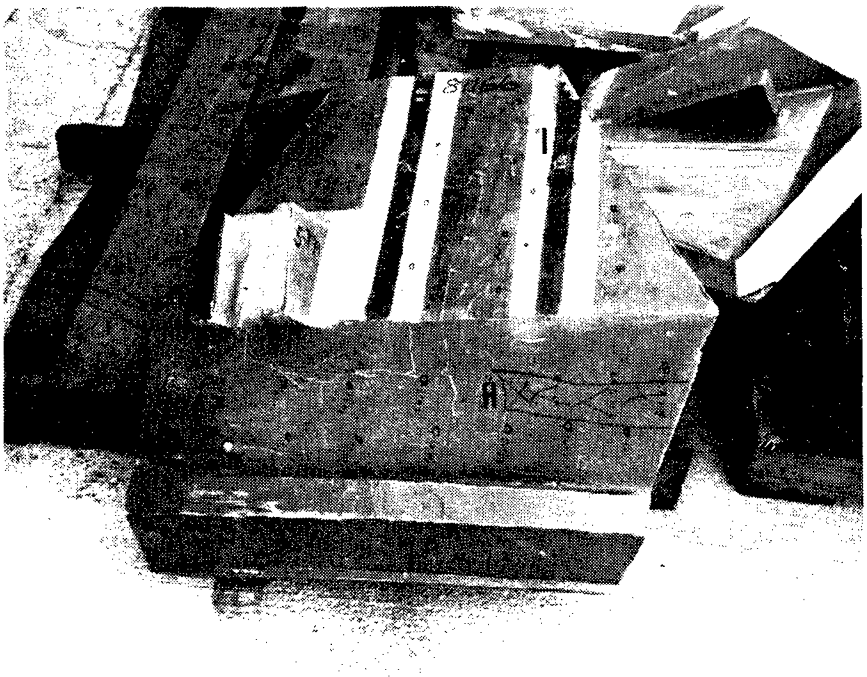


Figure A-14 Test Bars H and I

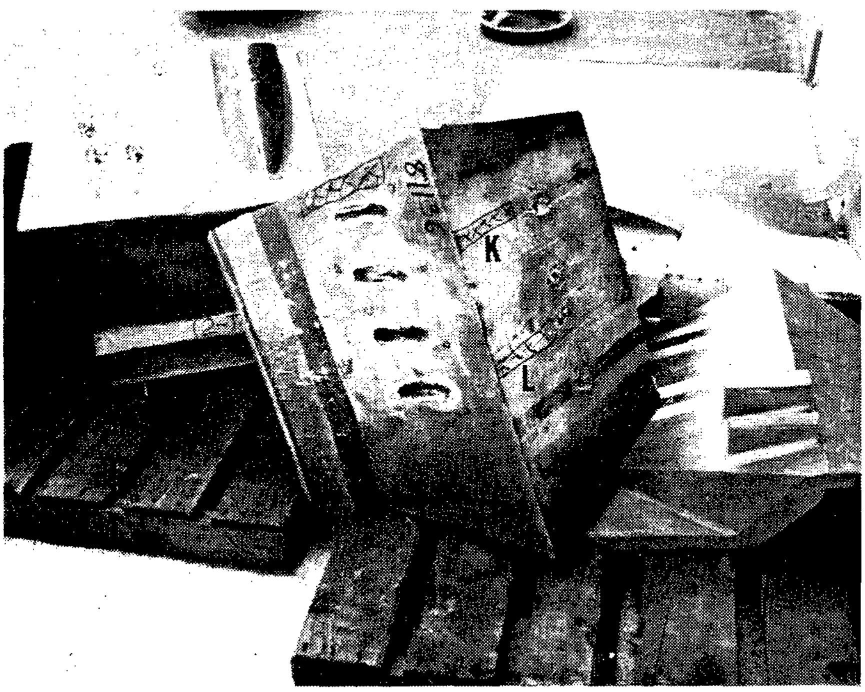


Figure A-15 Test Bars K and L

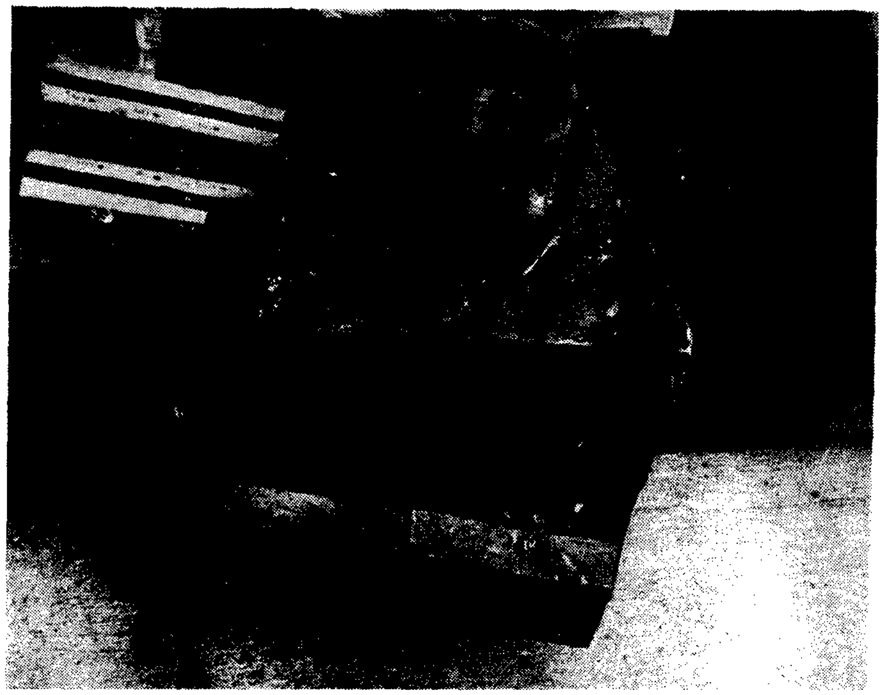


Figure A-16 Test Bars M and N

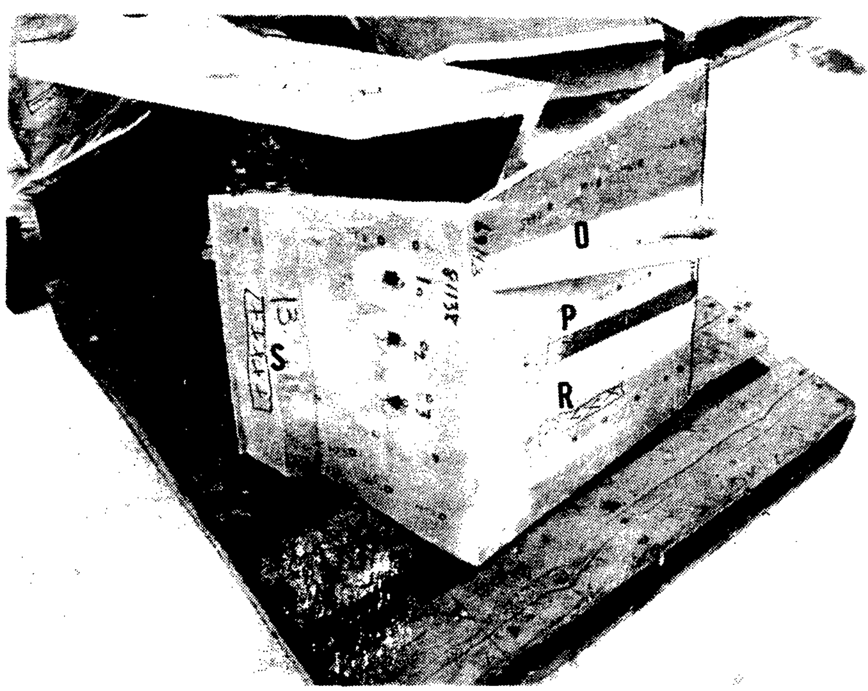


Figure A-17 Test Bars O, P, R, and S

Figure A-18 Test Bars T, U, and V

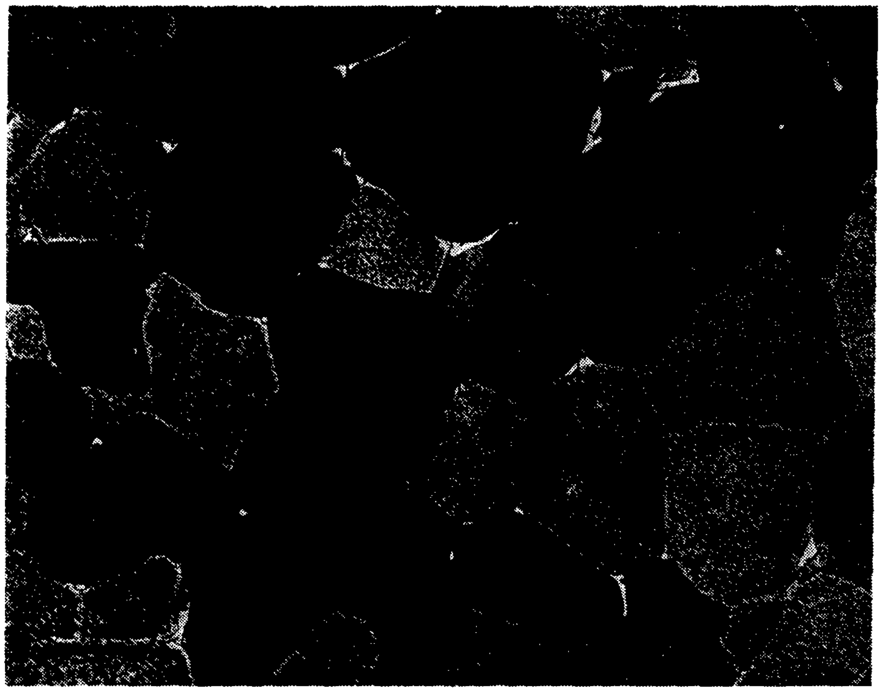


Figure A-19 Photomicrograph of Chilled Area of – T4 Temper Section (Specimen 'U').

(Structure consists of Cu_2FeAl_7 (blades), Cu-Al eutectic (white globules) and $CuAl_2$ (fine precipitate) in a matrix of aluminum solid solution. This structure is typical of A206.0-T4.)

Etchant: Keller's Reagent 100×

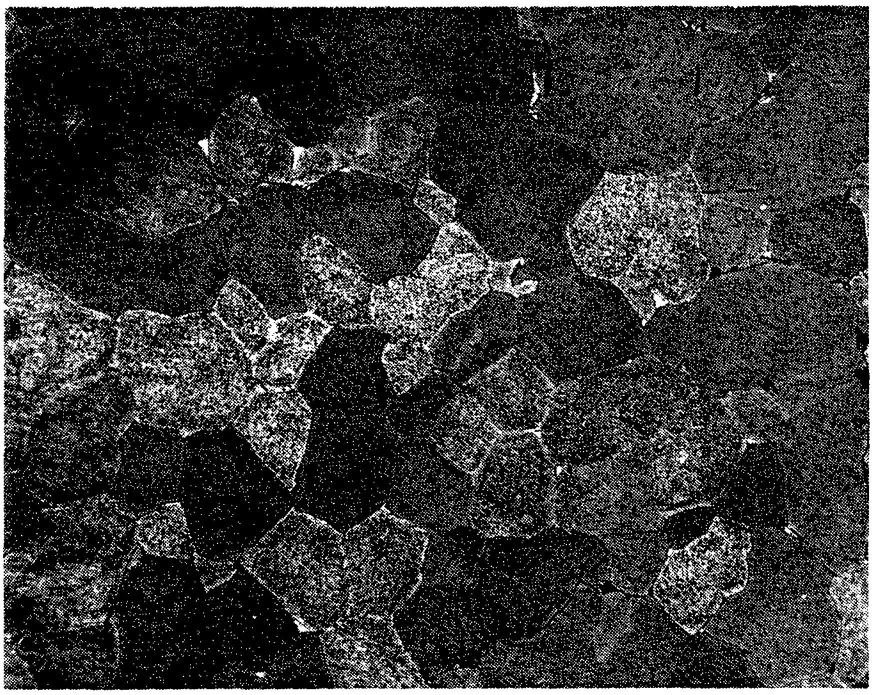


Figure A-20 Photomicrograph of Risered Area of – T4 Temper Solution (Specimen 'A').

(Structure is same as Figure A-12.)

Etchant: Keller's Reagent 100x

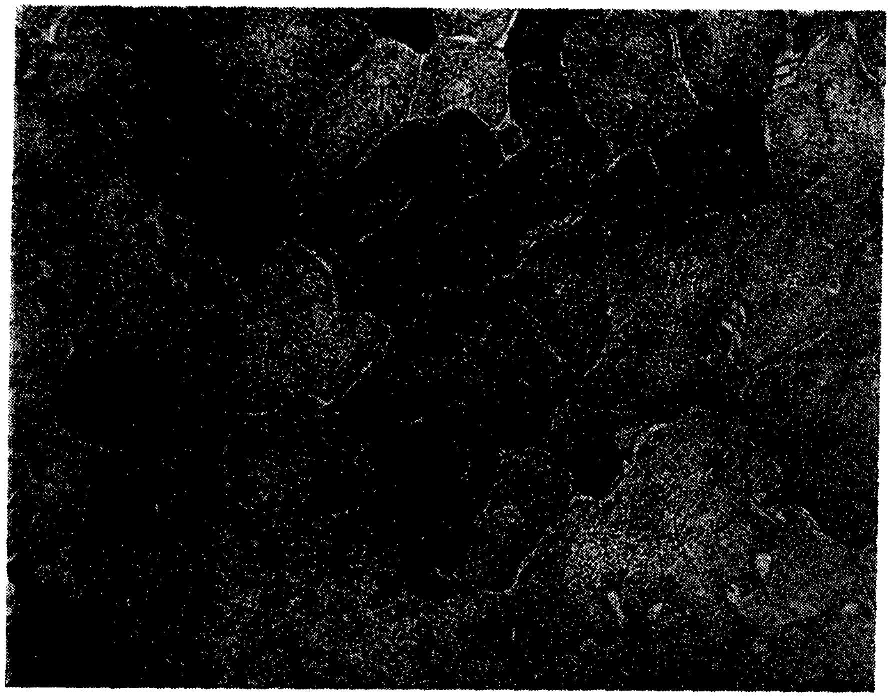


Figure A-21 Photomicrograph of Chilled Area of −T71 Temper Section (Specimen 'E').

(Constituents are same as Figure A-12, although the concentration of $CuAl_2$ precipitate in the grains is greatly increased. This structure is typical of A206.0-T71.)

Etchant: Keller's Reagent 100×

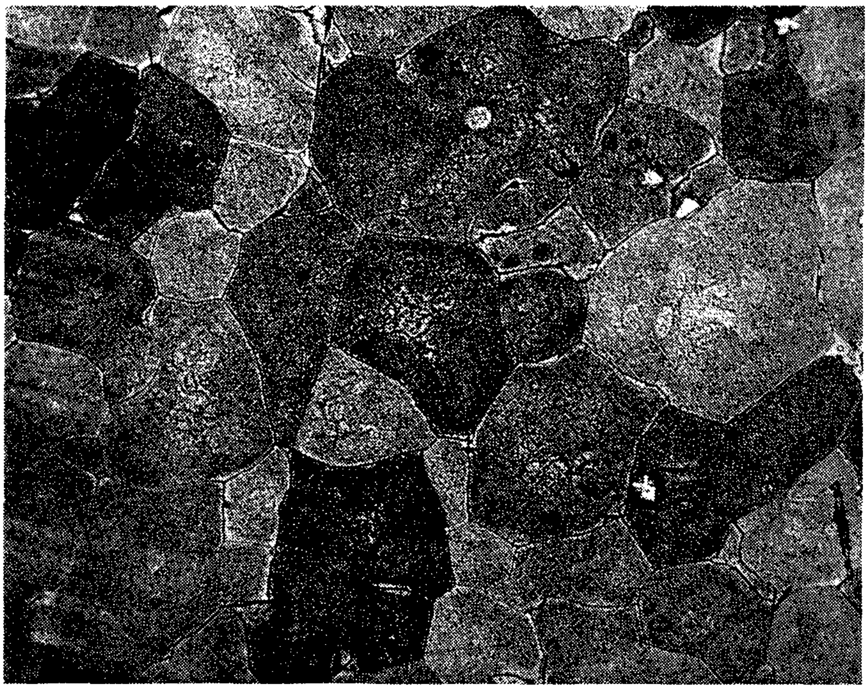


Figure A-22 Photomicrograph of Risered Area of – T71 Temper Section (Specimen 'I').

(Structure is same as Figure A-14.)

Etchant: Keller's Reagent 100×

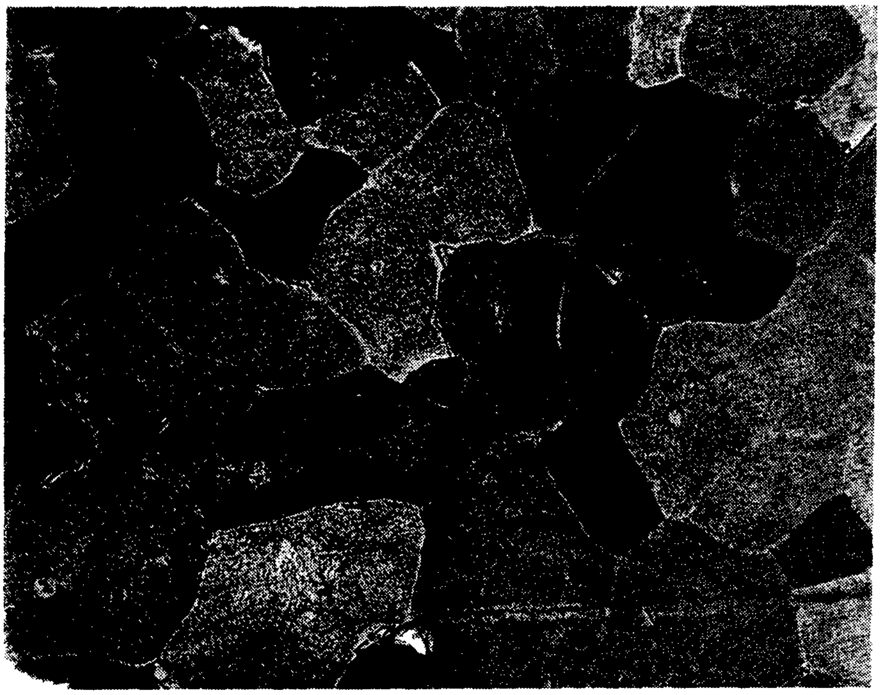


Figure A-23 Photomicrograph of Transition Area of – T71 Temper Section (Specimen 'F').

(Structure is same as Figure A-14.)

Etchant: Keller's Reagent 100×

APPENDIX C

APPENDIX C
WELDING OF A206

Objectives

- To determine the weldability of A206 and related effects of welding on castings. Of particular interest are mechanical properties of weld joints and how welding heat and weld metal dilution will affect joint performance.

- To determine an acceptability level for weld joints joining castings, and castings to wrought alloys.

Background

The welding of aluminum castings often has been disappointing in joint performance and quality. Acquiring a filler alloy which will closely match the chemical composition and mechanical properties, as well as having good welding characteristics, has been a major problem when the weldment is to be used "as welded". Welding process and procedure controls to limit the adverse affects of welding heat and dilution are difficult and sometimes costly. These problems can have a great influence on the mechanical performance of the joint. The quality of welds in aluminum castings also has been difficult to control due to the porosity content and the low elongation properties often associated with aluminum castings.

Approach

An initial test of the mechanical properties of welded A206 was performed to establish a basis for further testing. A sample production casting of A206 was sectioned to yield two test plates. The test plates were prepared as shown in Figure C-1 and welded using the GMAW* process (DCRP) with alloy 2319 filler

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*GMAW = Gas Metal Arc Welding
DCRP = Direct Current Reverse Polarity

wire. Alloy 2319 filler was chosen for this test because it has the best mechanical properties and the closest chemical composition to that of A206, and was commercially available. Tensile test specimens were then cut and machined from the weldment and tested to failure. The results are reported in CEL Materials Laboratory Report No. 812567 (FMC Corporation/Central Engineering Laboratories).

After evaluating the results of this test, a test plan was developed for further evaluation of A206 weldments. Cast A206 plates were acquired in two of the commercially available tempers, T4 and T71. A sample of wrought alloy 2219-T87 also was secured for welding to A206. The test plates were prepared as shown in Figure C-1 and welded in the combinations listed below using the welding procedure in Table C-1 and Figure C-2.

A206 - T4 to A206 - T4 Test as welded
A206 - T4 to A206 - T4 Postweld age to T71
A206 - T4 to A206 - T71 Test as welded
A206 - T4 to 2219 - T87 Test as welded
A206 - T71 to A206 - T71 Test as welded
A206 - T71 to 2219 - T87 Test as welded
2219 - T87 to 2219 - T87 Test as welded

TABLE C-1

Welding Process GMAW		Constant potential DCRP
Filler metal		1/16" 2319 wire
Shield gas		Argon, 100%
Shield gas flow rate		55 cfh
Welding energy:	1st pass	268-280 A @ 27-27 V
	Other passes	270-290 A @ 27-29 V
Welding travel speed		15 in/min (avg)

A "control" test plate was cut from the original A206-T4 cast plate material; tensile test specimens were then cut and machined from each of the weldments and the control sample.

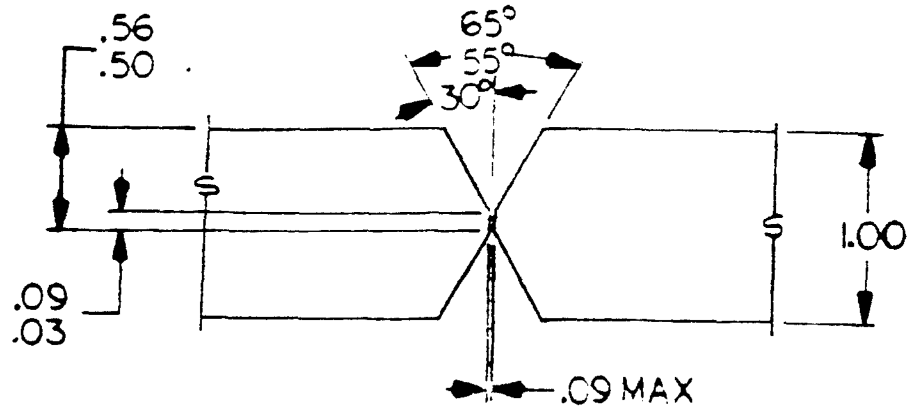

Figure C-1. Joint Geometry

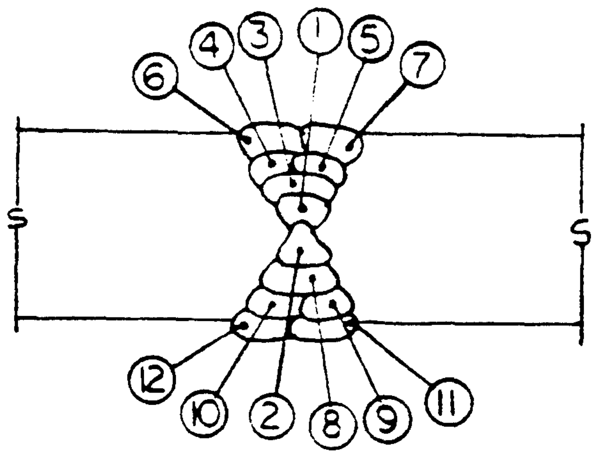

Figure C-2. Pass Sequence

In separate tests, A206-T4 was welded to wrought alloys 2219-T87, 5083-H323 and 7039-T61 using different filler alloys for each test. Mechanical tests and corrosion studies on the weldments are in progress. The results of which will be reported in the Phase II report of this cast aluminum alloy program.

Results

The results of the tensile tests are shown in CEL-MEL (Materials Engineering Laboratory) Reports 820837 and 820909. In Table C-2 the test values were averaged and then grouped and averaged again for comparison.

TABLE C-2 TENSILE TEST RESULTS

	TS	YS	ELON.
A206.0-T4 (control sample)*	61.0	37.6	23.0
A206.0-T4 to A206.0-T4 (Post weld aged to T71)	39.1	33.5	3.2
A206.0-T4 to A206.0-T4	37.1	28.8	4.5
A206.0-T4 to A206.0-T71	38.1	27.5	5.2
A206.0-T4 to 2219-T87	40.5	27.4	5.3
AVERAGE	38.5	27.9	5.0
A206.0-T71 to A206.0-T4	38.1	27.5	5.2
A206.0-T71 to A206.0-T71	31.7	30.2	2.5
A206.0-T71 to 2219-T87	37.8	28.8	3.3
AVERAGE	35.9	28.8	3.7
2219-T87 to 2219-787	38.7	26.8	4.3

*See Laboratory Report No. 820909, page C-13.

Conclusions

The testing of welded A206 is by no means complete. The results of these tests do not clearly indicate predictable mechanical properties of joints welded with 2319 filler alloy. However, other filler alloys should be investigated to determine which alloy will yield the best "as welded" mechanical properties. A206 alloy filler is now available in weld wire form and also should be tested. Other tests should be performed on welds that have been solution heat treated and artifically aged. These tests should indicate the highest obtainable properties of welded A206

It can be concluded from the tests performed that A206-T4, welded with 2319 filler alloy and postweld aged, performed slightly better in the tensile and yield strength categories than A206-T4 in the "as welded" condition. However,

A206-T4 in the "as welded" condition showed the highest elongation values versus A206-T4 postweld aged, A206-T71 and 2219-T87. Although these averaged results are not conclusive in themselves, they do indicate that A206-T4 in the "as welded" condition may be suitable for any application in military vehicles. In Phase II of this program FMC will be ballistic testing weld joints and weld repaired areas to evaluate their ballistic performance.

Supporting Test Data

MATERIALS ENGINEERING LABORATORY

TEST REPORT

TARGET DATE:	RESPONSIBILITY:	CHARGE NO:	WP DOCUMENT NO:	LAB NO:
	1 JFS	480312628	0028b	820837

REQUESTOR: C. Braafladt — 2 March 1982

DIV/CO. NAME: OED-SJ

STREET: M/D 320

TELEPHONE: 2566

SUBJECT/PART NAME:

SUBJECT: A206 Weldment Test Plates

SIZE: 12" x 12" & 12" x 6"

SPECIFICATION: A206 Aluminum Weldments, Plant 7.

SUPPLEMENTARY INFO:

MFGR: Eck Industries

LOT SIZE: 6

P.O. NO: 356 F 13

NO. TEST PCS: 6

INFORMATION DESIRED:

Mechanical Testing

See attached instructions.

KEY WORDS: PO 356F13

RESULTS:

11 March 1982

Table C-3 shows the results of the mechanical tests conducted on the submitted samples. The control samples (unwelded A206-T4) contained shrinkage porosity, and two of the three test bars failed prior to yielding. A macrograph of the three fractured control test bars is shown in Figure C-3.

TABLE C-3
MECHANICAL PROPERTIES

Material	Sample	Ultimate Tensile Strength (KSI)	Yield Strength (KSI)	Elongation % in 2"
A206-T4 (unwelded)	A	29.5	*	<0.2
	B	22.5	*	<0.2
	C	39.1	37.6	2.5
2219-T87 to 2219-T87	A	37.9	26.9	4.5
	B	38.0	26.4	4.0
	C	40.1	27.3	4.5
A206-T71 to A206-T71	A	29.0	28.2	2.5
	B	32.0	30.6	3.0
	C	34.1	31.9	2.0
2219-T87 to A206-T4	A	41.2	28.3	5.0
	B	38.5	25.4	6.0
	C	41.8	28.5	5.0
A206-T4 to A206-T4	A	29.4	27.5	2.5
	B	41.4	30.3	5.0
	C	40.7	28.6	6.0
2219-T87 to A206-T71	A	40.6	29.7	4.0
	B	36.4	**	3.0
	C	36.4	28.0	3.0
A206-T4 to A206-T4***	A	37.6	32.8	3.0
	B	41.1	33.2	3.0
	C	38.7	34.6	3.5
A206-T4 to A206-T71	A	38.8	27.6	5.5
	B	37.3	27.2	5.0
	C	38.4	27.6	5.0

*Failed prior to yielding.

**No yield point obtained due to extensometer problem.

***Aged at MEL.

FMC

Figure C-3. This macrograph shows the three fractured control test bars. The test bar on the right had only two small areas of porosity (dark areas indicated by arrows), but porosity was extensive in the other two bars.

MATERIALS ENGINEERING LABORATORY

TEST REPORT

TARGET DATE:	RESPONSIBILITY:	CHARGE NO.:	WP DOCUMENT NO.:	LAB NO.:
	1 JFS	480312628	0028b	820837

REQUESTOR: C. Braafladt 22 March 1982

DIV/CO. NAME: OED-SJ

STREET: M/D 320

TELEPHONE: 2566

SUBJECT/PART NAME:

SUBJECT: A206 Weldment Test Plates

SIZE: 12" x 12" & 12" x 6"

SPECIFICATION: A206 Aluminum Weldments, Plant 7.

SUPPLEMENTARY INFO:

MFGR: Eck Industries

LOT SIZE: 6

PO No.: 356F13

NO. TEST PCS: 6

INFORMATION DESIRED:

Mechanical testing

See attached instructions.

KEY WORDS: PO 356F13

TABLE C-4

Material	Sample	Location of Failure
2219-T87 to 2219-T87	A	Weld
	B	Weld
	C	Weld
A206-T71 to A206-T71	A	Base metal/weld
	B	Base metal
	C	Base metal
2219-T87 to A206-T4	A	Weld
	B	Weld
	C	Weld
A206-T4 to A206-T4	A	Weld/base metal
	B	Weld/base metal
	C	Weld/base metal
2219-T87 to A206-T71	A	Weld/base metal
	B	Base metal/weld
	C	Weld/base metal
A206-T4 to A206-T4*	A	Weld/base metal
	B	Weld/base metal
	C	Weld/base metal
A206-T4 to A206-T71	A	Weld/base metal
	B	Weld
	C	Base metal/weld

*Heat treated to T71 temper (390°F for 4 hours and air cooled) at MEL.

When the fracture passed through both the weld and base metal with the majority being in the weld, this was listed as weld/base metal in the failure column. If the majority of fracture existed in the base metal, it was listed as base metal/weld.

Because the control samples (unwelded A206-T4) failed prematurely due to shrinkage porosity, three additional tensile bars were tested (see next page).

MATERIALS ENGINEERING LABORATORY TEST REPORT

TARGET DATE:	RESPONSIBILITY:	CHARGE NO.:	WP DOCUMENT NO.:	LAB NO.:
	1 JFS	480312628	00114b	820909

REQUESTOR: C. Braafladt 9 March 1982
DIV/CO. NAME: OED-SJ
STREET: M/D 320
TELEPHONE: 2566

SUBJECT/PART NAME:
SUBJECT: A206 Test Plate
SIZE: 1" x 6 x 6"

SPECIFICATION: A206-T4

SUPPLEMENTARY INFO:
MFGR: Eck Industries
NO. TEST PCS: 1

BACKGROUND: Control sample in weldment test failed due to porosity.

INFORMATION DESIRED:
Other - Retest - .505 tensile bars (3).

KEY WORDS:

RESULTS:

22 March 1982

Material	Sample	Ultimate Tensile Strength (KSI)	Yield Strength (KSI)	Elongation % in 2"
A206-T4 (unwelded)	A	62.4	38.8	22.5
	B	61.2	35.1	23.5
	C	59.5	38.9	23.0

MATERIALS ENGINEERING LABORATORY
TEST REPORT

TARGET DATE:	RESPONSIBILITY:	CHARGE NO.:	WP DOCUMENT NO.:	LAB NO.:
	5 RIF	530397428	7288a	812567

REQUESTOR: C. Braafladt DATE: 810903
DIV/CO. NAME: OED-SJ
STREET: M/D 320
TELEPHONE: 2283

SUBJECT/PART NAME:

SUBJECT: Tensile Test Specimens, A206, Aluminum Weldment
SIZE: 1 1/2" x 8" x 3/4"

BACKGROUND: A206 Cast Aluminum welded itself using 2319 weld wire.

SUPPLEMENTARY INFO:
NO. TEST PCS: 2

INFORMATION DESIRED:
Mechanical Testing

KEY WORDS:

RESULTS:

810904

	TENSILE	YIELD	EL/2"
1.	39,200	30,400	4%
2.	40,400	29,700	5%

Specimens were machined to .505 diameter R1 test bars.
Both specimens broke in weld.

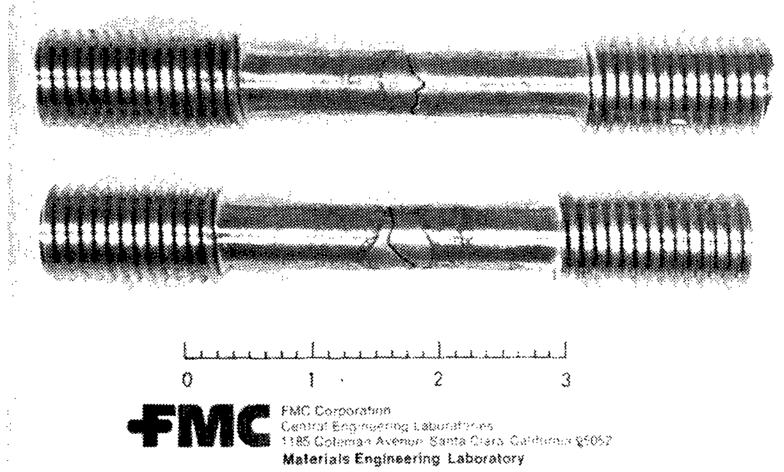

Figure C-4. Tensile Test Specimen Aluminum Weldment A206.
Cast aluminum welded to itself using 2319 weld wire.

APPENDIX D

APPENDIX D

ONE-PIECE TURRET CASTING vs SEVERAL PIECES

Most of the existing foundries pouring aluminum are limited by the size of the casting they can pour, or by the size of the casting they can solution heat-treat.

To permit maximum flexibility for the contractor to select vendors, and maximum competitive pricing capability, it has been proposed that the casting be split in two or more pieces for casting and solution heat-treating. The cast pieces would be welded together before final machining.

Four casting alternatives were suggested:

- One-piece casting
- Two-piece casting with vertical split
- Three-piece casting with horizontal split at the midline, and all the vertical plates making a "third" piece
- Four-piece casting with vertical cross split

D-1 TURRET AS ONE-PIECE CASTING

The merits of the alternative were:

- One-piece casting needs no welding other than for repairs. This results in a two-way saving.

  No machining is needed for edge preparation. This will free some of the machines being used for this type of work. An estimated time of 8 hours of router/machine and set-up time is required for edge preparation which will net an approximate savings of $312 per turret.

D-1 TURRET AS ONE-PIECE CASTING (Contd)

Castings will not need any welding, and hence no new welding fixtures will be required. A typical welding fixture to put turret plates together costs as much as $50,000. Elimination of welding fixtures, in turn, will free costly shop space and handling equipment which otherwise would be required to install, and operate these fixtures. Savings are estimated to be $50 to $100 per turret. At realistic present labor rates, this translates into savings of $525 per turret.

- One-piece casting will result in reduced production costs. As the casting size grows, the ratio of molten metal requirement to the finished weight of the casting decreases. This reduction in molten metal requirement per casting will use less energy, as well as reduce the amount of material to be cleaned off the casting at the foundry, thus reducing overall foundry costs.

- Fewer patterns will be required for production, hence lower tooling costs.

- Integrity of the casting is preserved. Welding various cast pieces may result in their relative shift from their basic location.

The demerits of this alternative are:

- Will result in less flexibility for FMC to select vendors and less competitive pricing.

- It will require special tooling to machine the opening for the access door to the 7.62mm machine gun.

- The high-cost, big casting can end up being scrapped due to cold shut or other defects which occur during pouring. If the turret is cast in smaller sections, any losses will be minimized.

D-1 TURRET AS ONE-PIECE CASTING (Contd)

- Many of the foundries are capable of heat-treating castings of the size of quarter section. A one-piece casting will have to be transported to other foundries for solution heat treatment, and this will add to its cost.

D-2 VERTICALLY SPLIT TWO-PIECE CASTING

The merits of this alternative were:

- Fewer cores will be required for casting. A cost reduction of 5% from a one-piece casting is estimated.

- Material handling and heat treatment cost would be reduced.

- Will permit high flexibility to select vendor and maximum competitive pricing capability.

The demerits of vertical split are:

- Welding through the base ring is a very costly and time consuming proposition. A "4x4" weld at the base ring could distort the casting.

- May result in stress corrosion cracking at or adjacent to the weld joints.

- Special welding fixtures will be required.

- Welding fixtures will use up costly shop place for installation.

- Will need additional handling facilities over and around welding fixtures.

D-3 HORIZONTALLY SPLIT THREE-PIECE CASTING

Merits of this alternative were:

- There will be more potential vendors and, hence, more competitive pricing.

- It will permit machining of openings of access door without any special tooling.

- Less costly rejections. It is less expensive to lose a part than a whole turret.

Demerits of this alternative:

- Three-piece casting will require added cost of:

- Welding and edge preparation for welding. It has been estimated previously that it will cost about $850 per turret for router/-machine, welding, and other setups for machining and welding.

- Direct and indirect costs of about $300 per turret may be incurred for building welding fixtures, plus their installation and use of floor space.

- Metal cleaning prior to welding; QA control on welds and reworking of defective welds will increase costs by $100.

All these additional costs add up to approximately $1250 for each turret.

D-4 VERTICAL SPLIT FOUR-PIECE CASTING

The merits of this alternative were:

- ° Fewer cores required for casting. It will result in slight cost reduction from a one-piece casting.
- ° Material handling and heat treatment cost will be reduced.
- ° Would permit greater vendor selection.

Demerits of the four-piece castings were:

- ° Heavy welds through the base ring at four different places will certainly distort the casting. Edge preparation time and welding time will result in heavy cost of putting the turret together.
- ° Special welding fixtures required for assembly.
- ° Handling equipment required for handling turrets in and out of welding fixtures.

D-5 CONCLUSION

From the information available, the one-piece casting trade-off is the best method. Sources for solution heat treatment of full-size casting were contacted. One vendor's negotiated cost includes total cost of solution heat treatment and for transportation. Special tooling can easily be developed for machining the opening for the access doors.

One-piece casting will eliminate shop control of handling, identifying, and storing of smaller castings. This will improve efficiency of operations and result in better control.

Vertically split two-piece or four-piece castings require weld through four-inch base ring. Time for edge preparation and welding will result in a very uneconomical casting. The casting is likely to distort, due to heavy welds.

One of the two foundries, contacted for price comparison of various alternatives, indicated that a three-piece turret casting will cost 10 percent to 15 percent more in comparison to one-piece casting. The other foundry estimates a cost difference of $3500 in favor of one-piece casting. The Contractor's cost of welding a three-piece casting turret will be over $1000. The accumulated cost differential between a three-piece casting, and a one-piece casting will be $2000 to $4500.

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